[illegible] PRACTICAL SCIENCE MANUALS

ELECTRICAL TRACTION

Ernest Wilson

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ELECTRICAL TRACTION.

BY

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PREFACE.

In the following pages I have endeavoured to deal with the principles relating to "Electrical Traction," and I have, I hope, incorporated sufficient descriptive matter for the purpose of illustrating the subjects treated of. Much of the information with regard to the Leeds Tramways which will be found in the text is given for the first time. I have also included descriptions of certain experiments which I have made for the purpose of this work. Descriptive matter and illustrations have been obtained from several sources, especially from the *Journals of the Institutions of Civil and Electrical Engineers*, and the *Northern Society of Electrical Engineers*, *Engineering*, the *Railway World*, and a Report of the Corporation of Sheffield on "Tramway Traction."

I have received much valuable information and many illustrations from the Westinghouse and the British Thomson-Houston Companies, for which I wish to express my obligations and thanks. Mr. R. W. Blackwell has also kindly lent me some illustrations.

I take this opportunity of acknowledging my indebtedness to Dr. John Hopkinson for the information he has furnished me with in the preparation of this work, and for the great kindness and assistance I have always received from him during the last seven years. My colleague, Mr. E. F. Herroun, and Mr. C. J. Evans, have kindly read through the proofs; and Mr. J. R. Salter and Mr. C. J. Evans have given me much assistance in the clerical part of the work. I have received help from Messrs. Tomkins, Woodfield, Strutt, Simpson, Greenbank, and Davey, past and present Student-Demonstrators in the Siemens Laboratory. To all these gentlemen I tender my thanks.

ERNEST WILSON.

KING'S COLLEGE, LONDON,
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ELECTRICAL TRACTION.

CHAPTER I.

INTRODUCTORY.

General Remarks.—Before considering the methods and means for the utilization of electrical energy for traction purposes, it will perhaps be well to briefly consider the agents used on railways or tramways, and for our present purpose we will divide the whole subject of line locomotion into two branches, namely, the main trunk lines of a country, and the shorter lines which include elevated and underground railways and street railways, or tramways.

The former branch is universally worked by steam, which will probably hold its own for many years. The Heilmann locomotive has, however, been proposed for this branch of locomotion. The idea is a simple one. The locomotive consists of a boiler and engine, the engine driving a dynamo or dynamos to generate electric current, which current is used for driving motors on the wheel axles. The advantages which have been claimed for this form of locomotive are that each axle of the locomotive, or indeed, of the whole train, can be a driving axle having motors upon them, which are supplied with current from the dynamo, and that hence a greater tractive force can be obtained; and further, that the motors can run at any speed in relation to the speed of the dynamo and steam engine on the locomotive; thus,

in ascending a steep gradient, the engine can be run at full speed with the maximum economy of steam, and the connection with the axle is such that the speed is reduced and consequently power gained, whereas in ordinary locomotives the power is proportional to the speed of the engine if we neglect variations of the cut-off and wire-drawing. But it must be borne in mind that although these advantages may or may not be real, they are obtained only at the expense of the extra cost and weight of the electrical apparatus. Moreover, there is the efficiency of the combination to be considered. We have first the conversion of mechanical into electrical energy, and then the conversion of electrical energy back again into mechanical energy, and this, as is well known, entails a loss of about 15 per cent.

With regard to the latter branch, let us first of all consider the tractive agents used on street railways or tramways. We have—

Horse,
Steam,
Cable, and
Electricity.

It is not our intention to enter deeply into the relative merits of these agencies, but one may say roughly, with regard to horse traction, the great drawback is that for tramway purposes the life of the horses is only from three to four years, and of course horseflesh is expensive. It is only where a great number of horses are used in a large scheme that any substantial profits can be looked for.

With regard to steam, the locomotive makes a good deal of noise and smoke; it is uneconomical, and must be supplied with good fuel. Steam locomotives are still running in many places; for instance, Leeds and Birmingham, and both these cities have taken up the propulsion of tramcars by electricity.

The propulsion of tramcars by means of an underground cable is in some cases undoubtedly most efficient; for instance, where the traffic is extremely heavy and the line fairly straight, or where there are very steep gradients. But naturally the maximum speed of the car can be but the speed of the cable, and the amount of power absorbed by the cable itself and its maintenance are serious items in the expenses of working the system. It is to be remarked that, whereas propulsion both by steam and cable has been in existence for a considerable time, propulsion by electricity has practically superseded these systems in the United States, that it has been considerably extended on the Continent, and is now making great strides in this country.

As regards electricity, the case is an extremely good one. Electricity may be looked upon as a form of gearing which gives extremely convenient connection between fixed engines and boilers or turbines, which generate the power, and the tramcars, which are propelled by it. Some of its advantages over steam are that it is noiseless and clean, and that in the station inferior fuel can be used where there are proper appliances; and, since the whole of the power is produced on the same spot, this can be carried out much more economically than in the case of a locomotive having to produce its power as it goes along, as well as to carry the weight of the fuel. One of its great advantages over the cable system is its extreme flexibility; for instance, the power station can be situate some distance from the track, at a site where water may be easily and cheaply obtained, where the cost for the cartage of fuel, etc., is at a minimum, and where land is also cheap, or where there exists suitable water power; and on the overhead trolley system the conductors or feeders can be taken almost anywhere without much trouble or inconvenience, whereas with the cable system enormous trouble and expense is necessarily incurred in large towns and cities where there are numerous gas, water, and service pipes which may have to be moved.

Perhaps the best basis of comparison is to compare the actual cost of driving a tram-car one mile under the different systems. The following figures represent roughly the average results obtained in practice.

Horse	9*d* to 12*d*.
Steam	12*d*.
Cable	9*d*.
Electricity	5*d*.

The ratio of working expenses to receipts with electrical traction averages 50 to 60 per cent.

If we look at the growth of electricity as applied to traction we find that it has been very rapid. The year 1888 marks an epoch of great activity in the United States of America, since in that year about 200 miles of horse tramways were converted into electrical. Since then electricity has continued to make such headway, that in 1896 over 12,000 miles of electrical tramway system were actually laid, employing 40,000 cars, and it is computed that £50,000,000 sterling has been expended in electrical tramway work in the United States. With regard to Europe, probably 1000 miles covers everything at present, but it is developing with great rapidity. Although we have in the United Kingdom some of the very earliest instances of electricity being applied to traction, yet we can boast of having done very little in this direction; and probably one reason which has conduced to this is that in the United Kingdom the electrical engineer has not had such a free hand as in America, since the legislation is totally different and very severe. The rail or track itself has to be very carefully laid and constructed, owing to the Board of Trade regulations with regard to leakage currents; in fact, in every direction we see that the British tramway engineer has had great difficulties to contend with.

There is no doubt that electric traction in the United Kingdom is beginning to make very great progress, and

the Light Railways Act, which was passed last year, will, no doubt, facilitate this, since it provides that "light railways" can be worked by electrical traction.*

Before the passing of this Act the method of procuring powers was very expensive, and the regulations with regard to construction severe. No district requiring facilities of transportation need be deprived of its "light railway" at the present time. The sixteen approved schemes up to June, 1897, that is within a year from the passing of the Act, and the twenty-eight further applications for "Orders" lodged in May last, show that this Act is being appreciated; and, although no line has yet been constructed under it, there can be no doubt but that it is a thoroughly practical measure.

Steam and electricity will be the motive powers brought into competition; and, although in some cases steam is undoubtedly the power to adopt, the relative advantages of these agents are generally pretty evenly balanced. Out of the sixteen schemes approved, four are to be worked by electrical traction, and the rest by steam. Of the twenty-eight new applications, electricity is proposed for seven, with three cases in which electricity is an alternative.

General Regulations.—It will be well to briefly review a few of the general regulations of the Board of Trade with regard to tramways, and also the general considerations with regard to speed and the forces to be dealt with.

The Board of Trade have power to issue, and do issue from time to time, regulations for securing the public safety, and bye-laws with regard to particular tramways worked by electrical traction. For example, regulations dated 11th of February, 1897, were issued regulating the use of electrical power on the Blackpool Tramways (see Appendix, pp. 225–230). Amongst other requirements, these regulations state that every motor carriage shall be

*** See "The Light Railways Act, 1896," with notes, etc., by Evans Austin, M.A., LL.D., Barrister-at-law. London: Reeves and Turner.**

fitted with a governor which cannot be tampered with by the driver, and which shall operate so as to cut off all electric current from the motors whenever the speed exceeds ten miles an hour. The speed at which carriages shall be driven or propelled along tramways shall not exceed the rate of eight miles an hour, and the speed at which carriages shall pass through facing-points, whether fixed or movable, shall not exceed the rate of four miles an hour. The speed shall not exceed the rate of four miles an hour at certain places such as crossings, or where traffic is heavy, etc.; that no two carriages shall enter any passing place from opposite directions at one and the same time. Further regulations are that the wheels shall be fitted with brake appliances, which can be applied by a screw or treadle, or by other means, and there shall be in addition an adequate electric brake (see p. 91). The regulations above referred to further provide that the motor-car shall be fitted with a suitable fender which will act efficiently as a life protector, and that it shall be free from the clatter of machinery; and any machinery under the carriage shall be concealed from view at all points above four inches from the level of the rails. Every train and carriage shall be fitted with a brake, and in addition to the conductor, there shall be a man on the front platform of the trailer car, whose sole duty it is to attend to the brake.

It is well known that it may require a supply from the mains of as much as three times the power to get a tramcar into motion as is required to keep it in motion when once started. In the case of railways, definite stopping-places are provided, and on single-line tramways definite stopping- or passing-places are imperative. But as usually worked, a tramcar stops at any point to pick up passengers. There is no doubt that greater economy will be secured by stopping at definite places only. To encourage this, if a fare of say $\frac{1}{2}d.$ or $1d.$ were charged for carrying a passenger from

one stopping-place to the next, and that if a passenger stopped a car in an intermediate position he were charged the full fare, he would rather walk to the nearest stopping place in order to save the extra fare which he would otherwise have to pay.

Adhesion and Tractive Force.—The energy supplied to the rail and the resisting forces have special interest for the traction engineer. The actual force in pounds necessary to start a motor-car or a train consisting of a locomotive and carriages, is a most important quantity, since the motors must be able easily to exert this force. Equally important is the question of adhesion between rails and wheels; for, if the motors do exert the requisite force, and skidding is the result, the load cannot be started. Perhaps one of the worst conditions is when the rails are wet and snowy. In this case, the adhesion or frictional resistance between rail and wheels is found to be as low as one-tenth the total weight on the driving wheels. The locomotives, with coaches and passengers, on the City and South London Railway, require about 140 amperes to start them. This current corresponds to a pull of about 216 lbs. per ton of locomotive, or 73 lbs. per ton of train, the weight of the locomotive being taken as 13·5 tons, and the complete train as 40 tons. In such a subway the conditions are not the same as in the open; but if 200 lbs. per ton on the driving wheels be taken as the basis for the lowest limit of adhesion, it will not be far wrong. No exact figure can be given, since the problem is complicated on account of gradients; but, unless absolutely necessary, cars should not be stopped on steep inclines, and should be supplied with sand in the event of their doing so. As an alternative to the use of sand the wheels might be magnetized, such method serving also as a brake.

Once the motor-car or train is in motion, the rate at which work must be done on the rails by the motors is to

be accounted for in three ways, all of which may be present at the same time.

First, the train has to be accelerated; that is, in a eertain time it must acquire a certain velocity. If the line be level, or rising in the direction of motion, this work must come from the source of supply. Matters can be greatly helped, as on the South London and Central London Railways, by making the trains store up energy by ascending to the station, and having this energy returned when descending on departure from the station.

Second, there is the frictional resistance offered by the rails, wind, etc., which is variable since these are influenced by the state of the rails which, on ordinary tramways, sometimes get filled with mud; and in the open, head winds have to be overcome.

Third, work must be done against the force of gravity if ascending an incline, whilst gravity does work on the train if descending.

Experience shows that it is not well to make motors which are only just able to do the work required; they should do this amply. A careful examination of the plans will enable the engineer to judge as to what must be the power of his motors; for instance, in the case of a railway, the distance between the stations, the gradients, the probable worst condition of the rails and the service, that is, the time required to get from station to station, and the maximum velocity are given. We might take as an example the City and South London Railway, which was electrically equipped by Messrs. Mather and Platt, of Manchester.* An examination shows that, perhaps, the worst section is between the Oval and Stockwell stations, for here on the down journey the gradient is comparatively severe. We may assume it to be 1 in 130 for the whole distance of about 4000 feet, which is comparatively great. We

* See papers by Hopkinson and Greathead, "Proc. Institution Civil Engineers," vol. cxii. p. 209, and vol. cxxiii. p. 39.

require the weight of the train necessary to carry, say, 100 passengers; suppose it to be made up as follows:—

	Tons.
Dead weight of passenger stock at 0·2 ton per passenger	20
100 passengers at 0·06 ton each	6
Locomotive	14
Total	40

Assume, as a programme of time, that the train requires half a minute to attain a speed of say 20 miles per hour, that is, nearly 30 feet per second; assume further, that it runs at this speed for $1\frac{1}{2}$ minutes, and then begins to slacken, and one minute is taken to slacken and stop at the station. It is clear that the maximum horse-power would be required during the first half-minute on the section we are considering. First, if acceleration be constant, we have during the first half-minute to do work at the rate of $\frac{\frac{1}{2}mv^2}{\text{time}} = \frac{40 \times (30)^2}{2 \times 32{\cdot}2 \times \frac{1}{2}} = 1118$ foot tons per minute $= 76$ H.P. Second, we have frictional resistance; for this we take 15 lbs. per ton of train. This is got by allowing 10 lbs. per ton of the train for the straight, and 5 lbs. extra per ton for curves. This is a fair average figure to take for railway lines. On account of this we must do work at the rate of $\frac{40 \times 15 \times 440}{33{,}000 \times \frac{1}{2}} = 16$ H.P., since the distance travelled is 440 feet. Third, we have to raise the whole weight of the train against the force of gravity through a distance of 3·5 feet, since the gradient is 1 in 130, and the horizontal distance 440 feet. The rate at which work is done on this account is $\frac{40 \times 2240 \times 3{\cdot}5}{33{,}000 \times \frac{1}{2}} =$ 19 H.P. The total rate at which work must be done during this first half-minute is then 111 H.P., and the motors must be capable of doing this. In actual working on this subway, the maximum speed would appear to be from 15 to 20

miles an hour, whilst the average, exclusive of stops, is stated to be 13 miles an hour. We see that, if a velocity of 20 miles per hour has been obtained, it requires only 35 H.P. to keep up this velocity on this incline, that is, about one-third of the maximum power.

The Application of $\frac{1}{2}mv^2$.—When a force f is applied to a mass m, the acceleration $= \frac{f}{m}$, and the velocity acquired when the body has moved through a distance s, with this acceleration is given by $v^2 = 2s\frac{f}{m}$; it follows that $fs = \frac{1}{2}mv^2$: fs is the work done in foot-pounds, say, while the force f acts through distance s, and $\frac{1}{2}mv^2$ is the energy of the mass m moving with velocity v. If the body has initially the velocity v_0 when the force f begins to be applied it has already energy $\frac{1}{2}mv_0^2$, and the gain of kinetic energy, equal to fs, is $\frac{1}{2}mv_1^2 - \frac{1}{2}mv_0^2$, where v_1 is the velocity after the force f has acted through distance s. This is the same as stating that $v_1^2 - v_0^2$ is equal to $2s\frac{f}{m}$. Consider a train moving down an incline a distance l under the influence of gravity alone. Then since it falls vertically through a certain distance h, which is given at once when l and the gradient are known, it follows that mgh is the actual work done on the train by gravity where g is the earth's acceleration. We can conveniently divide this into two quantities, namely, that portion of the total work which is taken to overcome frictional resistance of the line, which we may say is equal to 12 lbs. per ton of train, multiplied by the distance l in feet if we express work in foot-pounds, and the other portion which is the energy of the train in virtue of its velocity, and is equal to $\frac{1}{2}mv^2$, v being its final velocity. If we want to stop the train, clearly this work $\frac{1}{2}mv^2$ must be done upon something, whether it be a brake in the ordinary sense of the word, or a brake action due to the motors being converted into

generators, and returning the whole of this energy to the system except that part dissipated in the transformation; or the energy can be returned to the system during the time that the train is descending. This question will be seen to have an important bearing in electric traction since the dynamo is a reversible engine, and on steep inclines the subject is of great importance. Say that from rest to a speed of 20 miles an hour the tractive force varies from 3000 to 1500; the weight of the train is say 40 tons, and allowing 12 lbs. per ton for frictional resistance, we have 2520 effective for acceleration and work against gravity if necessary. Say we wish only to accelerate; then $2520 = \frac{40 \times 2240}{32 \cdot 2} \times$ the acceleration; acceleration equals 0·91 feet per second per second. Assume this goes on until v equals say 8 miles an hour, that is 11·7 feet per second. Then s equals 75·2 feet, and the time taken equals nearly 13 seconds. Suppose we now descend an incline, such that we can allow say one foot per second on account of gravity, and that the tractive force is about 1500, which allows 1000 lbs. for acceleration; we have 0·36 due to the motors; then, if this goes on until the velocity equals 30 feet per second, we have $900 = 2 \times 1 \cdot 36s + (11 \cdot 7)^2$; $s = 280$ feet. Also since $v_1 = v_0 + at$ where a is the acceleration, we have $t = 13 \cdot 5$ seconds. If the length of the train be considerable as compared with the distance one has to deal with, account should be taken of it. We see, therefore, that the total time from commencing is 26 seconds, the total distance travelled is 355 feet, the final velocity is 30 feet per second, and the train has kinetic energy $\frac{1}{2} \frac{40 \times 2240 \times (30)^2}{32 \cdot 2} = 1 \cdot 25 \times 10^6$ foot-pounds. Suppose we stop the train from 30 feet per second, and assume, say, that one-half of this energy is returned to the system; to get at the figure accurately we have the dissipation of energy due to friction and motors to consider.

Then if the time be, say, 12 seconds, the average rate will be $\frac{0 \cdot 62}{12} \times \frac{1}{550} \times 746 \times 10^6 = 70{,}100$ watts, which at 500 volts would give an average current of 140 amperes; or since the work returned equals $0 \cdot 62 \times 10^6$ foot-pounds, and the total weight of the train is 40 tons, this is equivalent to a fall of about 7 feet.

In changing from one service to another, say from $2\frac{1}{2}$ to 2 minutes, it must be remembered that since the work is nearly all done in starting, with frequent stopping-places, the tractive force will vary more nearly as the square of the speed if the change is effected by accelerating the velocity of each car instead of increasing the number of cars, and therefore heavier locomotives would be required.

CHAPTER II.

THE DIRECT-CURRENT MOTOR AND ITS CONTROL.

General Remarks on Tooth and Smooth Core Armatures.—There are two types of armatures which may be said to divide dynamos more into two distinct classes than the shape and number of magnet limbs, since these, after all, serve only to complete the magnetic circuit of the armature; these are known as slotted, or toothed, and smooth-core armatures. The original Paccinotti ring serves to illustrate the former, and the Siemens modern drum armature, the latter. Both classes are largely used; but, generally speaking, the smooth-core armature may be said to be favoured in Europe, and the toothed-core in America. Each has its advantages and disadvantages when compared with the other.

It has been experimentally demonstrated * that in non-synchronous alternate-current motors, the shorter the air-space, the more efficient the motor, since the power factor is increased; and, magnetically speaking, the direct-current machine would be improved by diminishing the length of the air-space. The toothed armature lends itself to diminished air-space; but this cannot be wholly taken advantage of in the case of direct-current dynamos, owing to consequent great armature re-action and sparking, and the excessive stresses due to magnetic pull if the armature gets slightly out of centre. So that the total line integral of magnetizing force is not much different in machines with the two classes of armature: in fact, with toothed-core armatures the air-space must have a

* See *Electrician*, 28th August, 1896.

greater length than is mechanically necessary on account of this. On the other hand, the smooth core gives the best results obtainable as regards sparking, unless specially prepared carbon brushes are used; but it introduces other disadvantages, which are, in whole or in part, not shared by the toothed core. It is, however, to be noted that the splitting up of the magnetic field into two parts adds reluctance to the cross-magnetizing force due to the armature, thereby diminishing its reaction.* Take the case of an alternate-current motor, in which the armature conductors are threaded through holes, punched out in a circle round the edge of the core discs. With fairly high permeability in the iron, one may say that the field within such passages is practically void of magnetism, and such a conductor could be moved about in such field without experiencing any considerable force. Yet force is transmitted to the armature proper, and the conductors play an important part. We may say, without entering into a full discussion of the subject, that force is transmitted to such armature, due, in part, to the current in such conductors. In ordinary toothed armatures we find slots which are sometimes partially closed in on the periphery, and although the conductors in such slots are not so perfectly shielded as is the case in an induction motor, yet the whole force acting upon the armature cannot act upon such partially shielded conductors. In the tooth armature, then, the force † on the conductors is not so severe, and they need not be supported with such special care, as regards driving, as is the case in smooth-core armatures. It is also well known that in the smooth-core armature, the conductors have to be stranded, or other precautions taken, to suppress induced currents in the copper itself. This is not the case with tooth armatures,

* See *Journal Institution Electrical Engineers*, vol. xxvi. p. 608.

† Since the above was written, a paper dealing with this subject has been read by Mr. Mordey. See *Journal Institution Electrical Engineers*, vol. xxvi.

since the shielding effect is so great, and therefore we find solid copper conductors. This fact tends towards cheapness in manufacture as well as increased efficiency, always assuming that the dissipation of energy avoided does not make any equivalent appearance elsewhere. It is usual in such dynamos to work with the teeth highly magnetized. For motors, perhaps the greatest advantage gained by teeth is the protection they give to the conductors against mechanical injury. One knows well enough how carefully smooth-core armatures have to be handled, whilst teeth give great protection. There is no doubt, also, that the tooth armature can better get rid of the energy dissipated in its core, since there is a good heat conductor in the tooth, connecting the air outside with the core itself. It is, however, usual to ventilate both tooth and smooth cores (see p. 41); that is, to provide internal air passages, so that the air in them, when acted upon by centrifugal force, is driven out and takes the heat away with it. Further than this, the motor is better off than the generator, since, *ceteris paribus*, armature reaction is not so great in a motor as in a generator, the magnetizing force due to induced currents and magnetic hysteresis being the reverse in a motor to what they are in a generator, so far as the current in the armature conductors is concerned. With regard to the fields of both motors and generators, cast steel has played an important part, and has, one may say, developed the multipolar dynamo. The ordinary tramway motor is usually a four-pole consequent type, and perfectly closed in and watertight. It will be well to discuss briefly the theory underlying the action of direct-current motors in general.

The Theory and Practice of Direct-Current Motors.—In an ordinary drum-armature, with two poles, let I be the total induction in C.G.S. units, m the number of effective convolutions, and E the electromotive force in volts induced by the rotation of the armature in this field. Then we have the well-known equation—

$$E = 2Im\frac{\text{revs.}}{\text{second}}10^{-8} \quad . \quad . \quad . \quad . \quad (1)$$

The torque exerted by the armature is equal to a certain force acting at a certain radius. Let T be this torque, then $T2\pi\frac{\text{revs.}}{\text{second}}$ is the rate at which work is being done mechanically by the armature, and is equal and opposite to the rate at which work is being done electrically on the armature, viz. EC where C is the current in the armature. We have, therefore, $T2\pi\frac{\text{revs.}}{\text{second}} = EC \times 10^7$ where T is expressed in C.G.S. units and C in amperes. Inserting the value of E, obtained above, we get

$$T = \frac{ImC10^{-1}}{\pi}\text{C.G.S. units} \quad . \quad . \quad . \quad (2)$$

The engineer generally requires this torque in foot-pounds. Since one foot-pound equals $1{\cdot}356 \times 10^7$ ergs, it follows that $T = \frac{Im\ C10^{-8}}{\pi\, 1{\cdot}356}$ foot-pounds. The whole of the power EC is not available at the shaft of the motor, since this includes the rate at which energy is being dissipated by journal, brush, and wind friction, and also by induced currents and magnetic hysteresis. It is, therefore, necessary to define what we mean by efficiency. We have (1) the efficiency of conversion as being the ratio of the mechanical power, given at the motor shaft to the electrical power EC; it is less than unity, on account of the dissipation of energy due to bearing, brush, and wind friction; induced currents and magnetic hysteresis. This efficiency should, in a well-designed motor of fair size, come out high. In the case of a Siemens machine, intended to give 11 kilo-watts at 880 revolutions per minute as a motor, the efficiency of conversion is 93 per cent. at full load.*

* See *Engineering*, 24th March, 1893.

(2) The electrical efficiency, being the ratio of the electrical power, EC, to the electrical power applied to the motor; it is less than unity, on account of the dissipation of energy in the armature and field-coil resistances. In the machine above referred to, this efficiency is 93 per cent.

(3) The commercial efficiency, being the ratio of the mechanical power given out by the motor shaft, to the total electrical power absorbed by the motor. In the Siemens machine, above alluded to, this efficiency is about 87 per cent. It must be remembered that this takes no account of loss due to gearing, which would exist in an ordinary tramway motor.

A subsequent test on the Siemens machines, above mentioned, running as motors, gives the results in Table I.

TABLE I.

Speed.	Watts given to motor at 104 volts.	Electrical efficiency per cent.	Efficiency of conversion per cent.	Commercial efficiency per cent.
620	13,016	91·4	95·1	86·9
613	10,686	91·7	95·3	87·4
618	7,691	90·6	93·5	84·7
630	4,826	87·7	89·3	78·3

In Mr. Greathead's paper, before the Institution of Civil Engineers,* a drawing is given of the motors on the Siemens locomotives, and is reproduced in Figs. 1 and 2. The motors MM (Fig. 3) are worked permanently in series with one another and an extra starting resistance, R. The magnet windings WW are placed in parallel, there being two on each motor. C is a current meter in the circuit, and S a reversing switch. The type of motor is the ordinary Siemens bi-polar drum machine with horseshoe magnets. The armature has a smooth core, which is fixed

* See *Proceedings Institution Civil Engineers,* vol. cxxiii. p. 39.

V-8

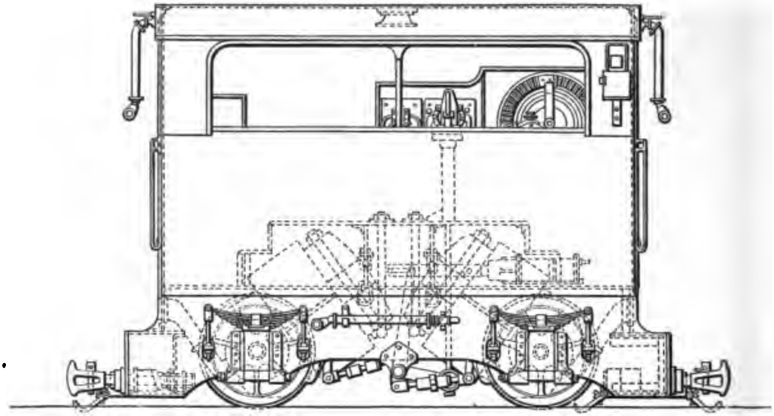


FIG. 1.

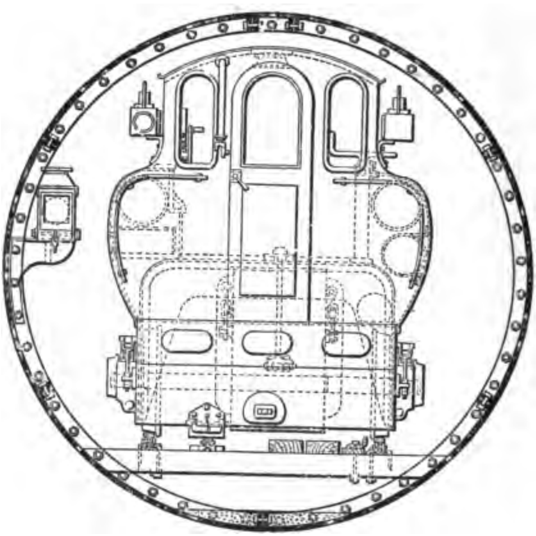


FIG. 2.

rigidly to the driving axle. The diameter of the driving-wheel is 2·25 feet, and the wheel base 6 feet; the shortest radius on the line is 140 feet. There are two motors on each locomotive, the magnets being supported from the axle by gun-metal bearings, and from the locomotive body by springs. The resistance of the four magnet windings

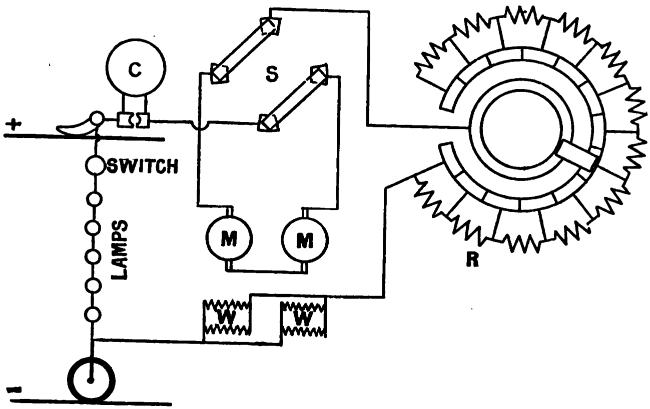


FIG. 3.

in parallel is 0·24 ohm, and each armature has a resistance of 0·18 ohm.* Therefore the total ohmic resistance, if R = O, is 0·6 ohm.

In Fig. 4 the current through the motors is plotted horizontally in amperes. The characteristic curve of one motor is given. This curve therefore gives the total induction in the armature in terms of the current in the armature and magnet circuit.† Let V be the potential difference in volts applied to the locomotive. This is assumed to be 450, and is supposed constant, and gives the

* See *Proceedings Institution Civil Engineers*, vol. cxii. p. 257.

† For construction of characteristic curve see Hopkinson's "Dynamo Machinery," and Thompson's "Dynamo Electric Machinery."

straight line V. If, when the motors are not rotating, the circuit be suddenly made, the extra resistance R is such that the current is 140 amperes. This, then, is the maximum

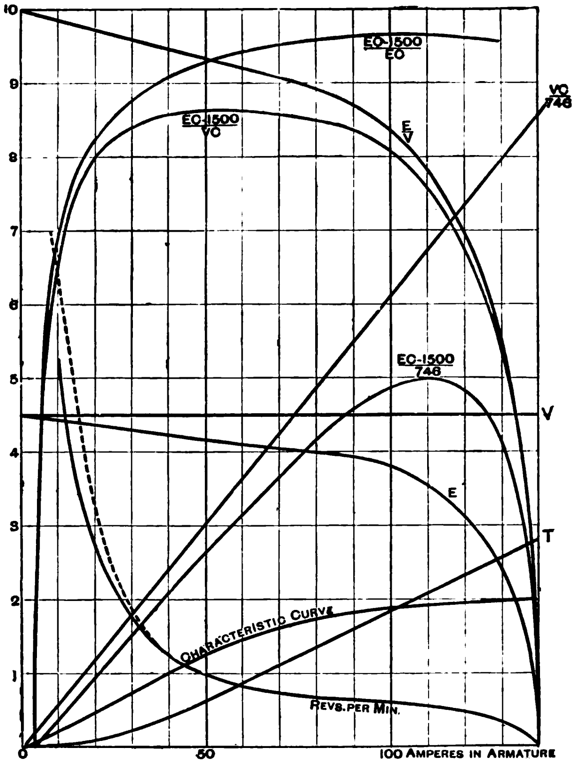


FIG. 4.

current we have to deal with. Suppose for the moment that $R = O$, then E, the electromotive force of the motor, differs from V by 0·6, multiplied by the current at any time. Assume this to hold from no current to 100 amperes,

and that then the curve for E be drawn as shown in Fig. 4. E is obviously zero at 140 amperes, and the curve of E between 100 and 140 amperes is determined by the value of R. Taking this curve E as drawn, and the characteristic curve for I, we can easily find the speed in revolutions per minute, say, of the motors for any current. This we obtain from equation (1); for revolutions per minute $= \frac{E}{I} \frac{60 \times 10^8}{4m}$, the $4m$ because there are two armatures in series. The brushes are rigidly fixed on the neutral line, and armature reaction is neglected. The revolutions per minute have been worked out, and give the curve in Fig. 4; for which the vertical scale must be multiplied by 200. It is obvious that the path of the E curve, as also the revolutions per minute, are under the control of the motor-man. The economy of power at starting depends upon the control of R, whilst the demand for current depends upon the track conditions and the time required to accelerate.

From equation (2) we see that the torque depends upon I and C for given motors. In the equation $T = \frac{ImC10^{-8}}{\pi \times 1 \cdot 356}$ foot-pounds, insert corresponding values for I and C, and we obtain the curve T in foot-pounds, Fig. 4. The rate at which the motors do work is obviously $T \frac{\text{revs.}}{\text{min.}} \cdot \frac{2\pi}{33{,}000}$ English horse-power, if T be expressed in foot-pounds. But this must be multiplied by the efficiency of conversion to get at the rate at which work is usefully done external to the motors, there being in this particular case no gearing. This is the same thing as multiplying EC by the efficiency of conversion. When gearing is employed the loss therein must be accounted for in the efficiency of conversion.

The electrical efficiency is easily obtained, since it is the ratio $\frac{E}{V}$, and is shown in Fig. 4. The efficiency of conversion, as also the commercial efficiency, are more difficult to

obtain in the absence of experimental data; an approximation can, however, be made. What we, of course, want is for any load, at any speed, the rate of dissipation of energy due to wind, bearing and brush friction, and magnetic hysteresis and eddy currents. This we *assume* amounts to 1500 watts in the two motors, and for our present purpose we consider it to be constant.

A series of differential tests have been carried out by the Author in the Siemens Laboratory, King's College, London, on two Siemens machines, each intended to give 11 k.w. at 880 revolutions per minute, to test the variation of this quantity with various currents in the armature at different speeds. The figures in Table II. give the results, and refer only to the motor; they show that this loss is greater the greater the speed; it is to some extent dependent upon the load for a given speed.

TABLE II.

Revs. per min.	Amperes in armature.	Volts across brushes.	Rate of dissipation of energy by magnetic hysteresis, and eddy currents in armature; and bearing, brush, and wind friction.
			Watts.
1273	42·1	107·0	589
1216	97·9	107·0	657
1130	99·2	106·5	633
1110	42·2	109·0	561
1060	72·9	105·0	499
1015	42·6	106·0	526
960	96·8	107·0	591
700	94·6	106·5	501
630	41·5	104·0	467
620	125·0	100·0	553
618	69·0	104·0	453
613	100·0	102·0	445
573	96·4	86·0	398
350	51·0	78·4	210

We have then $\frac{EC - 1500}{EC}$ and $\frac{EC - 1500}{VC}$ as the conversion and commercial efficiencies respectively. These are plotted in Fig. 4. $\frac{EC - 1500}{746}$ gives the horse-power delivered to the rail, whilst $\frac{VC}{746}$ gives the horse-power actually taken from the supply circuit.

The Acquirement of Magnetism.—The current cannot vanish, since the commercial efficiency is zero when the current is $3\frac{1}{3}$ amperes. We have seen that the torque depends solely upon I and C for a series-motor, I being a function of C, as shown by the characteristic curve. We have assumed that the induction I, corresponding to any value of C, always exists when C exists. This is not necessarily the case. To test this point the Author made some experiments upon a Siemens machine, the section of the magnets being $15 \times 4\frac{1}{2}$ square inches; the magnet winding had 1984 effective turns, having a resistance of 6·6 ohms. An extra non-inductive resistance of 21·5 ohms was placed in the circuit of this winding, and provision made for suddenly switching on 283 volts. The result shows that the current is a maximum in this circuit three seconds after switching on; but the induction in the armature takes eight seconds before being fully established, although most of the induction was induced in four seconds. If it were not for the considerable air-space, the induction would take much longer to attain its maximum value. In the case of a core twelve inches in diameter, the air-space being almost negligibly small, experiment shows that with such a magnetizing force as that just used, the magnetism takes fifty seconds to be completely reversed, in spite of the fact that the current is reversed almost immediately.* We see, therefore, that the initial torque in series

* See *Journal of Institution of Electrical Engineers*, part 116, vol. xxiv.; also *Engineering*, February 21, 1896.

motors having magnets of solid metal, is not nearly so great as one would infer from the characteristic curve. There are two remedies for this: first, lamination of the magnets; second, a sufficient magnetizing force always applied to ensure a large value for I initially. The practice at present in tramway work is to employ multi-polar motors. This will help matters even if the cores be solid, and when the cast steel shell has no great thickness. But, then, again, armatures are used with toothed cores, thereby diminishing the air-space. This will go against rapid acquirement of magnetism. In ordinary tramway work the motors are small, but in the case of electric traction on railways where heavy loads have to be dealt with, the motors become large. There is no reason, in such cases, why the motors should not be compound wound, the currents in the series and shunt windings helping one another, always provided that more than one shoe be supplied to collect the current in order to diminish the risk of breaking the shunt-circuit. The shunt-circuit would always provide an initially large value for I, and the series coils would only be called upon to give a smaller augmentation of the induction, thereby providing for the drop of potential due to armature reaction and current into resistance, and to prevent an abnormal current in the event of the shunt being broken. In such cases the assumption we made in connection with I and C would be in great measure removed, and greater economy secured. It must be remembered that the effect of temperature upon a shunt winding is to reduce the magnetizing current for the same applied potential difference, since copper alters its resistance about 0·4 per cent. per 1° C. This heating effect is not so important in the series-motor. A rheostat in the shunt-circuit is generally employed to compensate for heating of the coil. It appears that compound wound-motors are to be experimented upon on the Belgian railways (see *Electrician*, March 19, 1897.)

Agreement between Theory and Practice.—It is worth

while noting the agreement between the curves in Fig. 4, and the results actually obtained in working. If reference be made to Mr. Siemens' paper, read before the British Association, 1892, it will be seen that curves obtained on the locomotive are given. Four complete sets of curves are given for an "up," and four for a "down" journey. If the curves be examined it will be seen that certain portions of a particular journey give the same conditions, or nearly so, and therefore an average for the four can be taken.

Take sheets 2, 5, 8 and 11, Oval to Stockwell—

Sheet.	Miles per hour.	Amperes.	Volts.
2	13	80	400
5	13	60	420
8	13	60	420
11	13	70	420

Revolutions per minute = 162 for 13 miles per hour. The curves in Fig. 4 give for this speed a current of 65 amperes.

Take Sheets 1, 4, 7, 10, Stockwell to Oval—

Sheet.	Miles per hour.	Amperes.	Volts.
1	18½	30	440
4	19	30	460
7	19	30	405
10	19½	45	440

Revolutions per minute for 19 miles per hour = 237. The curves for this speed in Fig. 4 give a current of 40 amperes.

Take Sheets 1, 4, 7, 10, Elephant and Castle to Borough—

Sheet.	Miles per hour.	Amperes.	Volts.
1	10	100	460
4	10	100	440
7	10	100	440
10	10	100	440

Revolutions per minute for 10 miles per hour = 125. The curves in Fig. 4 give a current of 100 amperes. These results are in fair agreement with calculation.

Sheets 1, 4, 7, 10, Borough to City—

Sheet.	Miles per hour.	Amperes.	Volts.
1	22	50	443
4	25	25	455
7	20	25	450
10	20	40	480

Sheets 2, 5, 8, 11, Elephant and Castle to Kennington—

Sheet.	Miles per hour.	Amperes.	Volts.
2	5	103	420
5	5	120	420
8	5	120	420
11	5	120	440

The highest speed given in the curves is between the Borough and City. The curves in Fig. 4 would indicate 37 amperes. There is here for 40 and 50 amperes an indication of a shunt across the magnet windings; but with 25 amperes without a shunt the calculated speed would be greater than that actually observed. We shall see, at p. 27, that, instead of shunting the field, the motors can be placed in parallel for high speeds. Take a low speed, five miles per hour; the curves in Fig. 4 give 132 amperes for 62 revolutions per minute. This shows that the actual acceleration was not so great as shown in Fig. 4, and is, of course, controlled by the motor-man. It would appear that under these circumstances, from about 40 to 100 amperes, the locomotive was running without extra resistance, R, and without a shunt across the magnet windings. The effect of this latter is shown by the dotted extension of the speed curve, from 40 to 10 amperes. Since 140 amperes are necessary to start this locomotive and train, we can at once get the initial pull in pounds when the current is 140 amperes. The locomotive weighs 13·5 tons, and the complete train weighs, say, 40 tons with passengers. The pull in pounds per ton of locomotive = 216; and the pounds per ton of train = 73.

Series-Parallel Operation of Motors.—In ordinary tramway work it is usual to operate the motors in an

extended manner to that just mentioned in connection with the locomotives (Fig. 3). The motors are almost universally series wound, but are not permanently connected in series with one another. The control usually adopted is, first, to have the motors in series with one another and extra resistance. When the extra resistance has been cut out, simply the motors themselves are in series between the conductor and the rail. The next step is to place the motors in parallel, but this is not effected at once; for instance, the usual method is to first re-insert the extra resistance, place the motors in parallel, and finally cut out the extra resistance. This is known as the series-parallel control, and was patented by Dr. J. Hopkinson in 1881. For high speeds the magnet windings are shunted. We see from Fig. 4, that, as the speed of the motors increases, the horse-power they deliver to the rail decreases, and this with decreasing efficiency after about 20 miles per hour. But the motors work at high efficiency within the range of speeds experienced, omitting, of course, the initial stages. Suppose the speed be 526 revolutions per minute, that is, 40 miles per hour. With the motors in series and without extra resistance, R, the commercial efficiency is 80 per cent., and the current 20 amperes; that is, 7,200 watts are delivered to the line. Now place the motors in parallel. The total ohmic resistance is then 0·66 ohms. for one motor. If the current be 10 amperes in each motor, $E = 450 - 6{\cdot}6 = 443$ volts. Revolutions per minute = 1063. $VC = 9000$ motors in parallel. $EC = 443 \times 20 = 8860$;

$$8860 - 1500 = 7360. \quad \frac{7360}{9000} = 81{\cdot}8\%.$$

Under these conditions as to tractive resistance, the motors in parallel do work at the rate of 81·8 per cent. of VC at 1063 revolutions per minute, whereas when in series they do work at the rate of 80 per cent. of VC, at 526 revolutions per minute, VC being the same in each case. Suppose the current is 20 amperes per motor, and

they are in parallel. VC in this case = 450 × 40 = 18,000, as against 9,000 when in series. E = 450 − 13 = 437. Revolutions per minute = 500. EC = 437 × 40 for the two motors. EC − 1,500 = 15,980. Commercial efficiency = 88·8 per cent. Under these conditions as to tractive resistance the motors in parallel do work at the rate of 15,980 watts, at 89 per cent. efficiency; whereas, at practically the same speed, when in series, they do work at the rate of 7200 watts, at 80 per cent. efficiency. In series, the motors would do work at the rate of 15,500 watts, at 86 per cent. efficiency; but the speed would be 244 revolutions per minute. We see, therefore, that for high speeds the motors can with advantage be placed in parallel, and it is usual in traction work to carry this into effect; that is to say, to change over from series to parallel for the higher speeds. Suppose the current be 80 amperes, that is, 40 amperes per motor in parallel. Then VC = 450 × 80 = 36,000 watts. E = 424. Revolutions per minute = 291. EC = 33,920. EC − 1,500 = 32,420. Commercial efficiency $= \frac{32{,}420}{36{,}000} = 90{\cdot}1$ per cent. From the watts delivered to the rails we can at once deduce the horse-power and pounds pull at radius $\frac{27}{24}$ feet. Table III. gives these figures in better form for comparison.

TABLE III.

SERIES.

Revs. per minute.	VC.	Watts delivered to Rails.	Commercial efficiency per cent.	H.P. delivered to Rails.	Force in lbs. at radius $\frac{27}{24}$ feet.
526	9,000	7,200	80	9·65	85·7
244	18,000	15,500	86	20·8	398·0
138	36,000	30,500	85	40·9	1380·0
123	45,000	36,500	81	48·9	1890·0

PARALLEL.

1063	9,000	7,360	82·0	9·87	43·3
500	18,000	15,980	89·0	21·4	200·0
290	36,000	32,420	90·0	43·5	700·0
271	45,000	40,200	89·3	53·9	929·0

It might be found with motors in parallel that one is doing more work than the other. If nothing wrong with the connections can be found, the motor which is doing least work can be made to do more by giving it a slightly longer air-space; for instance, by placing a thin sheet iron packing strip between the junction of the halves of the magnetic circuit. This will weaken the field of this motor, and make it tend to run at a greater speed before generating a given electromotive force, E.

The curves in Fig. 5 are taken from Mr. Baylor's paper, recently read before the Institution of Electrical Engineers (vol. xxvi. of the journal), and illustrate the saving of energy when series-parallel control is substituted for control simply by resistance, the motors being in parallel. The average amperes for the first 18 seconds are 43, and 62 in the two cases.

Within the limits of Table III. the motors in parallel deliver from 2 to 10 per cent. more power to the rails at from 102 to 120 per cent. greater speed. The question really turns on the horse-power delivered at a certain speed and efficiency; if, for instance, 54 H.P. is required at 270 revolutions per minute, clearly the motors should be in parallel. In series at 244 revolutions per minute, the motors deliver only 21 H.P. to the rails. It would appear, then, that the requirements of the service on the South London Railway are such that the motors, as constructed, can be connected permanently in series, with the magnet windings shunted for high speeds if necessary. At the same time series-parallel control might have been employed with advantage.

Hamburg may be cited as an interesting example, since out of some 300 cars only about 50 are worked by two motors and series-parallel control, the rest are single motor-cars. This is not universal, and it is considered better

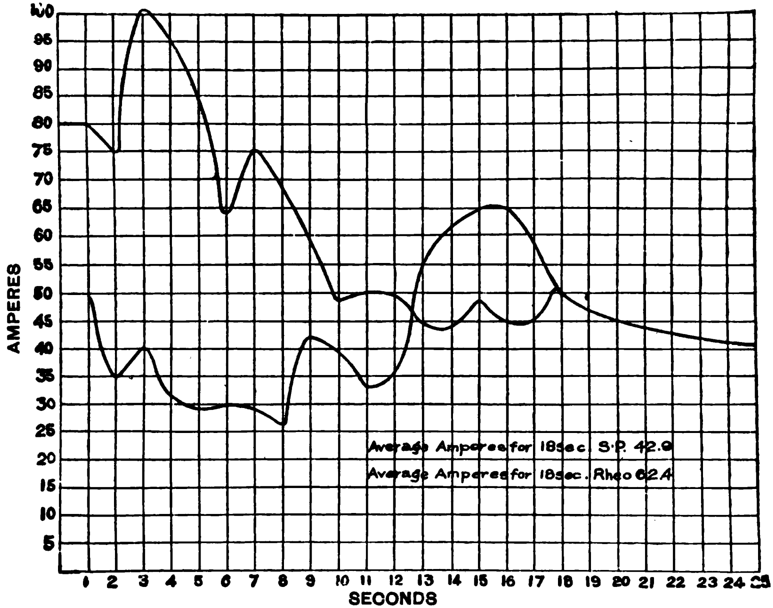


FIG. 5.

practice to employ the series-parallel control in tramway work. The higher the range of speed the more valuable does this method of control become.

Effect of Variation of Applied Potential Difference on Efficiency.—It is interesting to see the effect of variation of potential difference applied to the locomotive upon its efficiency, speed, etc. Imagine V has dropped to 300 volts, and that we take 18,000 watts from supply, the motors

being in parallel. Current is 60 amperes ; E = 280 ; revolutions per minute = 420 ; EC − 1500 = 15,300 ; commercial efficiency = 85 per cent. Comparing this with VC = 18,000, and V = 450, we see that the speed is reduced from 500 to 420, and the efficiency from 89 to 85. To obtain the speed of 500, and do work at the same rate, a greater current would be demanded ; and this is what would happen, since the motor-man must maintain his speed at the expense of current. In this particular case he would have to shunt the fields, since there is no extra resistance to be cut out. We see, therefore, what an important bearing the constancy of potential difference over the whole system has upon efficiency.

The Controller and Extra Resistance.—The apparatus used in practice for effecting the successful operation of motors on the series-parallel control system is of great importance, and is the outcome of much experience and trial.

One of the early difficulties encountered in the operation of motors on tram-cars was the sparking at contacts of the controlling apparatus. The action of a magnet on the electric arc is well known, and its adoption in tramway apparatus of all kinds where arcs may occur has, no doubt, had a great influence upon the success of electrical traction. This idea is due to Professor Elihu Thomson, and the patents for magnetic blow-out apparatus are owned by the British Thomson-Houston Company.

The Thomson-Houston "K2" Controller, in which this magnetic blow-out is employed, is shown in Fig. 6, in which the magnet with one of its poles swung back on a hinge is clearly shown. This pole piece is so arranged that all the contacts on the vertical spindle are, when the controller is shut up, in the magnetic field produced by such magnet ; and, therefore, whenever a contact is broken the field immediately blows out the arc. Many hundreds of these controllers are in use at the present time, and they are

adopted on the Leeds, Bristol, Dublin, and other lines in the United Kingdom.

In Fig. 6 the handle at the top of the controller serves to operate the vertical spindle and its series of contacts,

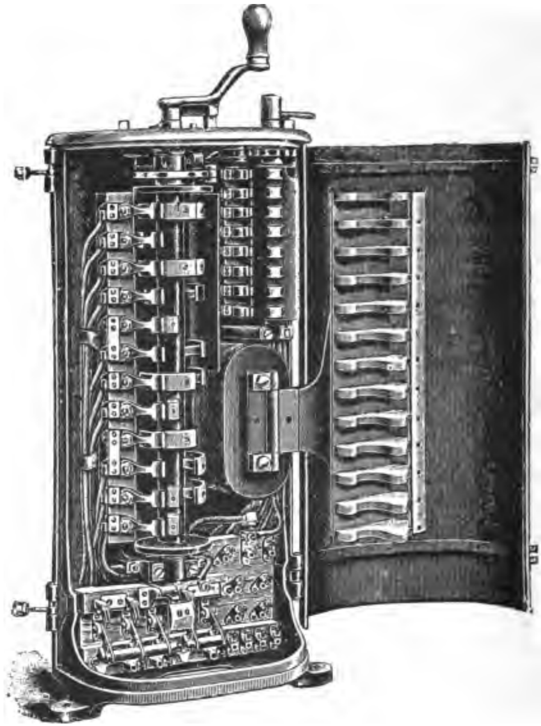


Fig. 6.

and interlocked with this is a subsidiary spindle shown to the right which operates the reversing switches, the arrangement being such that the reversal of current cannot take place until the main switch has broken contact with supply.

The K2 controller is so arranged that when the handle is placed on the first notch the motors are in series with one another and the full extra resistance. Notches 2 and 3 reduce this resistance to one-third and one-twelfth respectively. Notch 4 places the motors in series across the mains without extra resistance. Notch 5 prepares for placing the motors in parallel by first shunting the fields, and then placing only one motor across the mains with one-third the extra resistance in its circuit. Notch 6 places the second motor in parallel with the first, the one-third extra resistance still in series. Notch 7 reduces this extra resistance to one-twelfth. Notch 8 places the motors in parallel across the mains without extra resistance. Notch 9 shunts the fields of the motors in parallel for higher speeds. Notches 1, 2, 3 are merely for the purpose of cutting out resistance, and the handle should pass over them with fair rapidity; 4, 5, 6 are working positions, giving speeds suitable for level stretches; 8 and 9 are positions for steep gradients and high speeds, and a pause should be made on each notch to enable the car to obtain the speed due to that position of the switch-handle. The addition of an extra reversing switch enables the controller to deal with four motors instead of only two.

The Westinghouse controller, No. 28A (Fig. 7), deals with the series-parallel control of two motors of from 25 to 30 H.P. A vertical steel shaft, terminating with the handle shown in the figure, is fitted with iron lugs, which are faced with copper, such lugs being insulated from the shaft by means of mica. These lugs make contact with a series of projections on the side of the controller frame, such contacts depending upon the position of the operating handle. A series of fibre rings are placed between the lugs on the shaft, for the purpose of preventing any intersparking which might occur, such rings turning with the shaft. This controller has a series of seven definite positions or notches at which the controller handle can be

FIG. 7.

placed, and which are very easily found by the conductor of the car. If the handle be placed at the first notch, the circuit is closed on the two motors in series with extra resistance, which is cut out in steps until notch number four is reached. The fifth position places the motors in parallel with extra resistance in the circuit which is partly cut out on the sixth position. Notch seven places the motors in parallel directly on to the line without extra resistance.

The small handle to the right is for reversing the direction of current in the field coils, so as to reverse the direction of rotation. The two handles are interlocked with each other in such manner that the reversing switch cannot be operated unless the circuit be broken by the main handle. Further than this, if it is necessary to cut either motor out of circuit by means of a special short circuiting plug—and this might be necessary if one motor became disabled—the car starts on the first notch, and is full on at the fourth, beyond which the handle cannot be turned.

The construction of a suitable rheostat or resistance for motor work is one of the most important considerations in the success of electric traction. Coils of wire, such as German silver, stretched between insulators in the manner usually adopted in the test-room, are not a success on a car or locomotive. The vibration and extension due to heating give great trouble. In some cases such spirals are supported in plaster-of-Paris, or sand, in iron tubes. Fig. 8 gives the Westinghouse method of dealing with this problem. Iron or nickel steel band is wound on a former with mica insulation between, and free access is given to the air to come in contact with such coil internally and externally. In the figure, one such coil is shown, and combinations of such coils can be made by securing them to a cast-iron frame, the number depending upon the requirements of the rheostat.

The Tramway Motor.—In traction work it has become

general to use multi-polar motors with at least four poles. In a four-pole motor two coils are used on poles

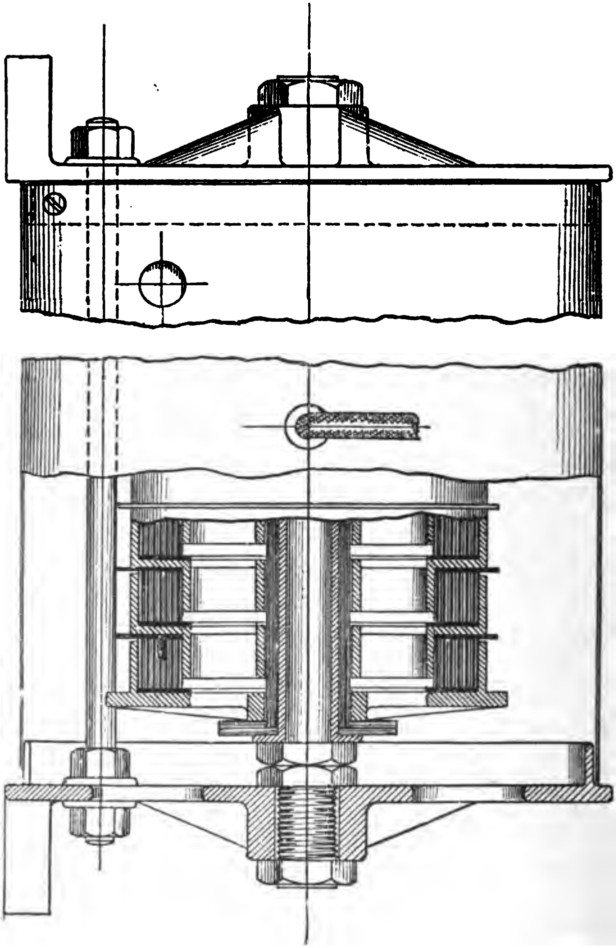


FIG. 8.

on opposite sides of the armature; the other two poles, at right angles to these, being simply short projections on the cast steel shell which protects the motor from injury and seals it up so that water cannot get into the working parts. The armature of these motors is, perhaps, the most important part, and deserves special attention. The practice now is to use the two-circuit four-pole drum armature, the conductors being placed in slots on the surface. This gives a very strong construction, and the strain upon the copper conductors is thereby diminished.

As an example of the best practice, we may mention the motors made by the Westinghouse Company. Their present standards are what are termed "No. 12A," 25 and 30 H.P.; and "No. 38," 50 H.P. In these armatures the number of slots and the number of commutator bars are each prime to the number of poles; for instance, in the 12A type, there are 47 slots and 93 commutator bars. Each slot contains wires belonging to four separate coils, two of which are attached together before insertion. Since there are 47 slots and 4 ends per slot, there are 188 ends. But the commutator has only 93 parts, and therefore two ends have to be discarded. These are the ends of any one coil on the armature. The diagram in Fig. 9 shows a four-pole armature, in which there are 19 slots and 37 commutator parts, each number being prime to the number of poles; and shows the "dead coil," as it is termed, this being placed in position to make the mechanical balance perfect. The long, radial lines are the upper conductors, and the short ones the lower conductors in a slot. It will be seen that the upper conductors in one slot are connected to the lower conductors in a slot three in advance, and this is continued all round the armature. Although only one conductor is shown for a particular coil in the diagram, it is obvious that each coil can enclose the teeth round which it passes as many times as is required for the purpose in view. This number is necessarily

dependent upon the speed, volts, and induction in the armature. The pitch, as it is sometimes called, or the arc of circle embraced by the coil, is a variable. For instance,

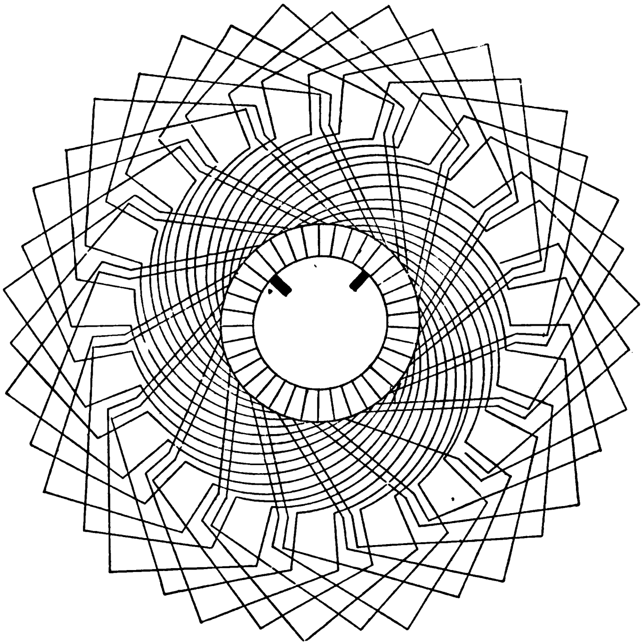


FIG. 9.

in the armature referred to, the coil embraces an arc of a circle given by placing it in slots 1 and 11; but in another instance, the coils are placed in slots 1 and 12, although the total number of slots is the same—viz. 47.* On the other hand, the Westinghouse, No. 38, 50 H.P. armature has 45 slots, each containing three

* This variation of pitch is well set forth in "Armature Windings," by Messrs. Parshall and Hobart.

separate coils, making six ends per coil. The commutator has 135 bars, two leads being connected to each. There is, therefore, no "dead" coil in this armature, and yet 135

FIG. 10.

and 45 are each prime to the number of poles. It is only necessary to place the brushes on the neutral line at 90° apart, in this type of armature. The brushes are in all cases made of carbon, the carbon being held in a small

FIG. 11.

holder, and lightly pressed upon the commutator by means of a spring. The brushes are shown in position in the diagram. The coils are machine wound, and carefully insulated before being placed in position. Fig. 10 shows

No. 12A armature partially wound. Fig. 11 shows a completely wound armature, with half its connections made to the commutator.

If I be the total induction in the armature due to one pole, the average E.M.F. induced in the turn on the armature during one quarter of its revolution is—

$$\frac{2\mathrm{I}}{\text{time of } \frac{1}{4} \text{ rev. in secs.}} = \frac{8\mathrm{I}}{\text{time of 1 rev.}};$$

and since there are $\frac{m}{2}$ effective turns between the brushes

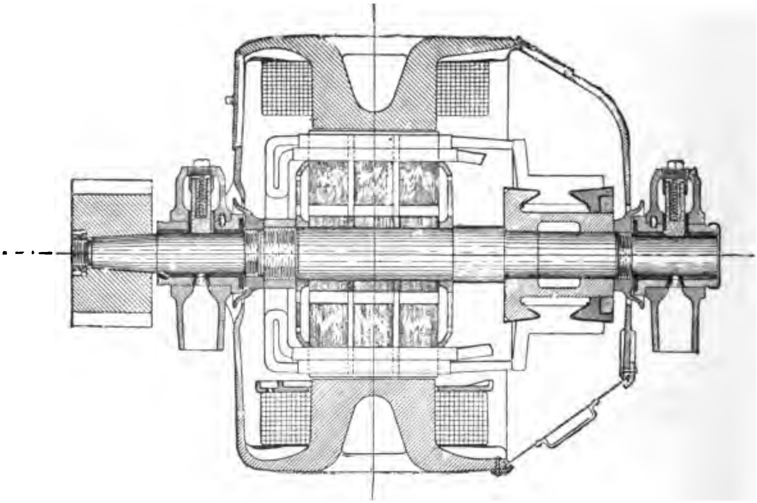


FIG. 12.

where m = total number of convolutions on the armature, or $2m$ = the total number of wires counting all round, it follows that, if m be large enough, the machine would give as a generator a practically steady uni-directional electromotive force of $4\mathrm{I}m \times \frac{\text{revs.}}{\text{sec.}}$ C.G.S. units ; or $\frac{4\mathrm{I}m}{60} \times \frac{\text{revs.}}{\text{min.}}$

$\times 10^{-8}$ volts. This is our familiar equation connecting these quantities (see p. 16), only we now have four poles instead of two.

Fig. 12 gives a cross sectional elevation of the motor in detail, the two poles shown having field coils, the two others at right angles to these are without coils. The motor is what is generally called a "consequent pole" machine. The armature core is provided with internal passages for the purpose of ventilation—a method largely used at the present time in generators as well as motors. The centrifugal force, acting upon the air in these radial passages consequent upon the rotation, sets up circulation which keeps the armature cool. The sketch shows in detail the bearings and method of lubrication, and the steel pinions at the end of the motor shaft. Fig. 13 shows one of the armature discs, the internal passages for air, and the armature conductors in position in a slot. In these motors the brushes can be fixed rigidly on the neutral position between two poles. It is fortunate that this is the case, for adjustment of the brushes to suit various loads would be costly and troublesome. It is well known that in a motor the armature reaction is not so severe as in a generator. The eddy currents and magnetizing force due to hysteresis in the armature core are the same in a motor as in a generator; but in the latter they help the current turns on the armature, whilst in the former they oppose, thereby causing less reaction.

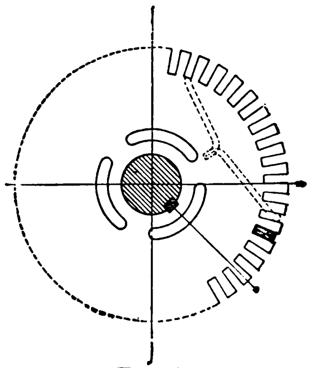
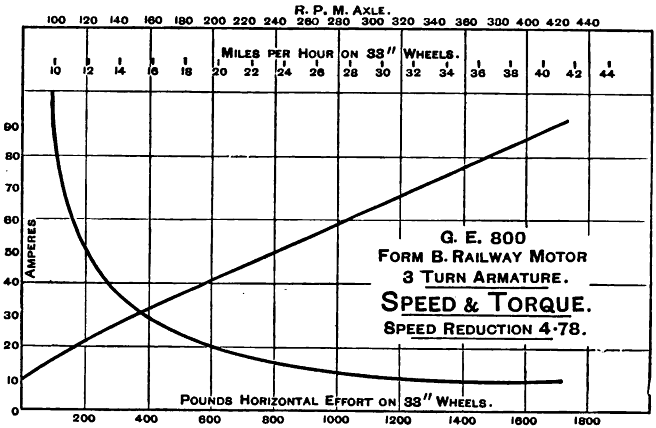
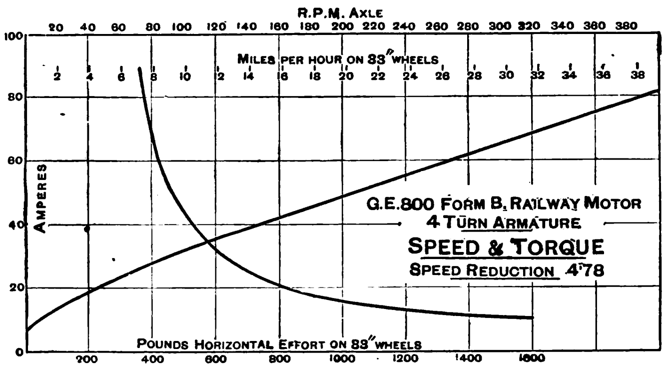


FIG. 13.

The General Electric Company's Motors.—Figs. 14 and

15 give the speed and torque curves of a G.E. 800 motor, with 3 and 4 turns per armature slot respectively, given





Figs. 14 and 15.

to the Author by the British Thomson-Houston Company. The speed reduction is 4·78 to 1. Data taken from these curves are as follows:—

Armature.	Force in lbs. at rim of 33 in. wheel.	Amperes.	Revolutions per minute of motor.
3-Turn	800	50	124
4-Turn	1060	50	93

It is interesting to compare the same motor with the two windings. For the same current, say 50 amperes, the field will be the same; we should therefore expect the torque to vary as the turns, $1060 \times \frac{3}{4} = 795$ as against 800. Further, the total mechanical energy developed by a motor in a given time varies as I*m*C × revolutions per minute. We have $800 \times 124 = 992$, also $1060 \times 93 = 986$.

Another set of curves, relating to a G.E. 1200 motor, give with a ratio of reduction of 3·53 to 1 :—

Armature.	Force in lbs. at rim of 33 in. wheel.	Amperes.	Revolutions per minute of motor.
2-Turn	1200	96	160
3-Turn	1820	96	110

In this case $1820 \times \frac{2}{3} = 1210$ as against 1200; also $1200 \times 160 = 192 \times 10^3$; whereas $1820 \times 110 = 200 \times 10^3$.

The Testing of Motors.—In addition to the test of the motor or motors on the car itself (see p. 88), it is important to see that they will fulfil certain conditions before they leave the testing-shop. An accurate method for such testing is mentioned on p. 202; but, in any case, the motor should be run at the average speed it will experience in practice, say the speed corresponding to seven miles per hour of the car, for six hours, when it is developing the requisite torque. For instance, in the G.E. 800 motor (p. 42) the force at the rim of a 33-inch wheel through

single reduction of 4·78 to 1, is 800 lbs. in the three-turn armature. When inclosed, the armature and field under such working conditions should not exceed a rise in temperature on that of the surrounding atmosphere of the number of degrees to be stated in the specification. Such motors should be able to stand safely 50 per cent. overloading for short times.

The Author is indebted to the Westinghouse Electric and Manufacturing Company for the following particulars of a workshop test of their No. 46 500-Volt Railway Motor. The ratio of reduction between armature and car-axle is 4·86 to 1; and the duration of test one hour. During this time the motor developed a force of 1000 lbs. at the rim of a 30-inch car-wheel at a speed corresponding to about 8 miles per hour of the car. This is equivalent to doing work on the rails at the rate of 21 H.P. at this speed. At the end of the hour the armature had risen in temperature 49° C., the field 64° C., and the commutator 30° C. The current in the armature was 38 amperes, and the applied potential, 500 volts. The net efficiency cold was 80 per cent., and with an increased resistance of 20 per cent. this fell to 78 per cent. This test, the Author is informed, is much more severe than those which the motor would be subjected to under normal running conditions.

The Magnetic Properties of Cast Steel.—The shell of these inclosed motors is now made of cast steel, and this material has played an important part in the development of the tramway motor, in addition to the multi-polar generator. It is instructive to compare the magnetic properties of cast steel with good wrought iron.

The figures in Table IV. relate in part to a sample of almost pure iron tested by Messrs. Lydall & Pocklington,* which can be taken as a standard with which to compare the other samples given in the Table. This table gives

* See "Magnetic Properties of Pure Iron," *Proc. Roy. Soc.*, vol. 52, p. 228.

the magnetic induction per square centimetre, B, in terms of magnetizing force, H, both in C.G.S. units. Sample I. is the pure iron just referred to. Sample II. is an unforged steel casting. Sample III. is a steel forging furnished by Mr. R. Jenkins as a sample of forged ingot metal for dynamo-magnets. Sample IV. is of Low Moor bar forged into a ring, annealed and turned. These figures have been taken from a paper on the "Magnetic Testing of Iron and Steel," by Professor Ewing.*

TABLE IV.

Magnetizing force H	Magnetic induction B.			
	I.	II.	III.	IV.
5	12,700	10,900	12,300	10,900
10	14,980	10,320	14,920	13,120
15	15,800	14,350	15,800	14,010
20	16,300	14,950	16,280	14,580
30	16,950	15,660	16,810	15,280
40	17,350	16,150	17,190	15,760
50	—	16,480	17,500	16,060
60	—	16,780	17,750	16,340
70	—	17,000	17,970	16,580
80	—	17,200	18,180	16,800
90	—	17,400	18,390	17,000
100	—	17,600	18,600	17,200

Take magnetizing force 40. The pure iron, sample I., gives for B, 17,350 as against 16,150 for the steel casting, whilst the steel forging, sample III., gives 17,190. Both samples II. and III. are but little inferior to the pure iron, and are superior to the annealed wrought iron, which gives 15,760 for this magnetizing force. It will be seen, therefore, that steel castings can be produced which are equal to the best wrought iron, and therefore the castings for multi-polar

* See *Proceedings Institution of Civil Engineers,* vol. cxxvi. p. 185.

dynamos can be made much lighter than was formerly the case when cast-iron was used, since, with the cast-steel, the sectional area of the frame effective for magnetism need not be greater than the actual section of the magnet cores themselves, whereas for the cast-iron it was usual to make it about twice as great.

CHAPTER III.

OVERHEAD AND OVERGROUND CONDUCTOR SYSTEMS.

General Remarks.—Financially speaking, the most successful means of transmitting energy in the form of electricity to motor-cars on a tramway is, undoubtedly, the overhead trolley system. A copper conductor, connected to the source of supply, is fixed to and insulated from brackets, which are supported by poles placed at intervals along the route. Contact is made between this conductor and the one pole of a motor, or motors, on the car by means of a small trolley wheel, which is carried at the end of a flexible pole attached to the car roof. In another arrangement, contact is made with the overhead conductor by means of a transverse horizontal rod suspended by flexible end poles. The other pole of the motor, or motors, is connected almost universally to the wheels of the car, and hence to the rails, which form the return conductor. There are instances in which a second overhead conductor is provided, in which case a second trolley wheel is used to connect the other pole of the motor with the return, not using the rails as a return conductor at all. This latter type is called the "double trolley" system, and has advantages and disadvantages. Its advantages with direct currents are that little or no interference is occasioned to telephones or telegraphs, and there can be, in this system, no earth currents. Its disadvantages are its higher first cost, and the difficulty of suitably arranging the conductors at crossings. A modern and interesting example of this double trolley

system, in which the rail is also used as a return, is at Lugano in Switzerland, where the line, which is about three miles in length, is operated on the three-phase alternate current system. Another instance is that of Cincinnati, where the two overhead conductors transmit energy to the cars, the rails not being used as a conductor. There are not many instances of this system, but there are some hundreds of single trolley systems in which the rails are used as the return conductor. At the end of 1896 there appears to have been close upon 13,000 miles of tramway in the United States operated on the overhead trolley system, as against, at the most, 1000 miles for all classes in Europe.

An allied system to the overhead trolley is that in which a continuous conductor is carried on insulators above or near the surface of the ground. This system was probably the earliest adopted for the electrical transmission of energy to cars. It is, of course, out of the question for roadways, but it is used for elevated railways, underground subways, and, in fact, anywhere where the track is not used for any other purpose than the railway. We have instances of this system in the City and South London Railway, and the Liverpool Overhead Railway. Such conductors are also used on the Chicago Elevated Railway.

The transmission of energy to motors in a tramway is quite a different problem to the simple transmission of energy from, say, a generator to a motor at a fixed distance ; here a certain drop of potential takes place, and is allowed for. In an electric tramway the conditions, as regards potential difference, more nearly approximate to the supply of electrical energy from central stations for lighting purposes. The maximum potential difference, which the Board of Trade sanction, and which is almost universally used, is 500 volts. This is a potential difference which can be handled with tolerable ease in motor and apparatus, and is not fatal to human beings, but may be fatal to horses. The car is constructed to work properly at 500 volts, say, and, of course,

it must have this applied potential, or nearly it, at any part of the system. The importance of constancy of potential difference is pointed out at p. 30. This consideration makes the problem more difficult to handle, and we shall have to consider the various remedies adopted in practice.

Before commencing the design of any scheme, certain information must be obtained as to general matters. For instance, the service or frequency at which the cars must run, the average speed and the length of the line give the number of cars to be operated; and provision must be made for spare cars to meet greater demands upon the system, such, for instance, as at holiday times, or in summer, if the place is a pleasure resort, and also to replace breakdowns. In Great Britain the average speed of cars, including stops, may be taken to be about seven miles per hour. If v be this velocity and l the length of the journey in miles, then $\frac{l}{v}$ is the time taken for a car to complete the round trip. If the cars have to run at intervals of m minutes, then $\frac{l \times 60}{vm}$ gives the number of cars. Take, as an example, the Leeds Tramways (see p. 195); here the round trip is about fourteen miles. Assume that the average speed is seven miles per hour, then the car completes the trip in two hours. If the service is seven and a half minutes, then the number of cars is sixteen. The problem is, of course, influenced by consideration as to single or double track, and also in branch services, where the demands of the different branches vary.

The power taken to propel a tram-car is, as we have seen, an important item, and on a given system is greatly influenced by the nature of the track, as to whether there are steep gradients, sharp curves, etc. An ordinary tram-car, complete with motors, etc., to seat about 44 passengers, weighs, with passengers, about ten tons. At an average velocity of seven miles per hour, such a car can be propelled one mile, on ordinary lines, by the expenditure

of about one Board of Trade unit; that is, 1000 watt hours. A Board of Trade unit is equivalent to about 2,650,000 foot-pounds, or 1·34 H.P., acting or exerted for one hour. We have seen that the power taken to get a train under weigh is about three times the average power taken to keep it going when once accelerated. Take the average speed at seven miles per hour. The time for one mile is one-seventh of an hour. One thousand watt hours equals the watts multiplied by one-seventh hours. Therefore the watts = 7000; H.P. = 9·4; and, since the volts are assumed to be 500, the amperes = 14. We see that, whereas the average rate at which work must be done on the car is from 9 to 10 H.P., the maximum H.P. may be 33. According to Cunningham,* the power taken at Montreal equals about 260 watt-hours per ton mile. The average speed is 7·5 miles per hour. The cars are stated to weigh six tons, and on this basis we get 1·56 Board of Trade units per mile, per car, which, with passengers, might weigh ten tons. It must be remembered that Montreal is on a slope, and the gradients at right angles to the river are very severe. They are stated to be 1 in 10 and 1 in 8. In any case, contractors guarantee the propulsion of a tramcar, weighing about ten tons, one mile, at about seven miles per hour, by means of the expenditure of one Board of Trade unit. If the cars are many, say twenty or thirty or more, the average power differs less from the maximum power than if the cars are few. Suppose, in a certain district, there are two cars only; then they may demand 70 H.P. if they start together, which is very likely; whereas, if there are many cars, it is, one may say, almost infinitely improbable that they will all start at the same moment, and therefore the average power differs less from the maximum power.

In a simple system, where no precaution is taken to prevent drop of potential due to current in the line, the

* See *Journal Institution Civil Engineers*, vol. cxxiv., 1895-96, p. 287.

potential difference will fluctuate very much in the outlying districts, whereas, in the vicinity of the station, the fluctuations will be smaller. Although the Board of Trade issue no limitation as to the drop of potential in the working conductor itself, it is of importance for the successful operation of the line to limit it (see p. 30). This brings us to the important question of Feeders.

Feeders.—By the term "feeder" the Author wishes to imply any system by means of which energy can be given to the cars at distant points, which energy is transmitted from the power-house proper, by means other than the ordinary line and return. Suppose A is the power-house, then, in Fig. 16, we have a simple system, the cross lines

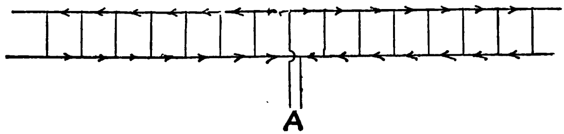


FIG. 16.

being intended to represent motors placed between the conductor and the rail. Such a system as we have seen is open to the objection that the fall of potential difference, as one proceeds to the distant points, becomes greater, and the fluctuations severe. The system might, of course, be tolerated on a short line.

Fig. 17 illustrates a simple system, to which feeders have been added. These consist of heavy conductors, which transmit energy directly from the station at A to the feeding-points; that is, the point where such conductors are attached to the working conductor and return respectively. Such a system has long been used in connection with electric lighting, and is well known. The South London Railway may be quoted as an instance.* In large

* See Dr E. Hopkinson, *Proc. Inst. Civil Eng.*, vol. cxii. p. 209.

installations the first cost of the copper is a great consideration in the design of feeders.

Fig. 18 illustrates another system of feeders. This system receives energy from the station at a high potential, thereby requiring a small conductor, since its size is in part determined by the current required to be transmitted. At the point where the energy is to be delivered to the system a motor-generator is placed. This consists essentially of two machines coupled together, the one a motor, which receives the energy from the station at high potential, the other a generator, which delivers this energy to the system at the lower required potential. In such a system of feeders the consideration is not altogether the first cost of the copper, which may be small, but also the first cost of the motor-generators, their efficiency, the housing and the attention they require. The tramway system at Dublin gives an illustration of this kind of feeder. Here energy is transmitted by means of three-phase alternate currents at 3000 volts to a synchronous motor, directly coupled to a generator, giving energy, in the form of a direct current, at 500 volts to the line. We note that in this case there is no storage except from the momentum of the moving parts.

Fig. 19 shows another system of feeders, which consists of storage-cells capable of delivering energy to the line and receiving energy from the station at A. This system has the advantage that the batteries can be steadily charged almost continuously, and when called upon can suddenly discharge energy at a great rate. This aspect of storage is important. An illustration of this system is at Leeds, where the simple feeder (Fig. 17) is also used in combination. As shown in Fig. 19, the current from the cells to the station takes path along the rails. A drop of potential will, therefore, occur on account of this independently of the cars.

The whole subject of feeders is one of great importance,

and is influenced by many considerations. An examination of the figures just given shows that one effect of a feeder is to seriously disturb the distribution of current in the rail return. Take Fig. 16, which represents a simple system of supply. Between A and one end of the rails the potential difference is that due to the gradually

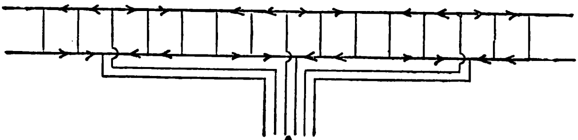


FIG. 17.

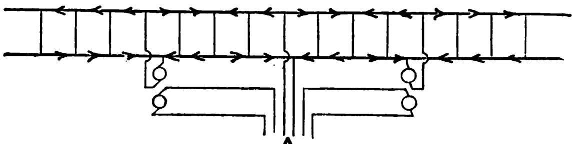


FIG. 18.

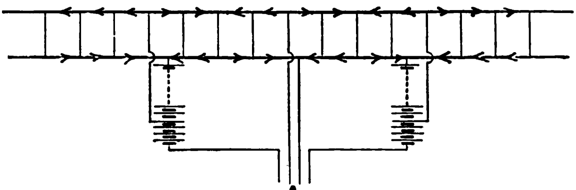


FIG. 19.

diminishing current into the resistance of the rail. A very stringent provision made by the Board of Trade, with regard to drop of potential in the rails, is that this shall not exceed seven volts (see Regulation 7, Appendix, p. 227), the object being to secure that the earth shall not be compelled to carry more current than necessary, on account of the injurious effects due to electrolytic action

on underground pipes. A little consideration shows that in Figs. 17, 18, 19, the drop of potential due to the current in the rails between the point A and where the feeder is attached, may be very small, although just as many cars are being operated as before. The fall of potential difference, then, between A and the feeding-points is no criterion that there are, or are not, earth currents. A safer condition would be to state that the maximum potential difference between any two points of the rails shall not exceed such a potential difference as it can be demonstrated will not be injurious. This matter will receive attention when we come to deal with the track itself, for which there are other regulations with regard to leakage (see p. 82).

With regard to the simple feeder system (Fig. 17), several conditions have to be decided before determining the size and number of feeders for a given line. If the feeder is to keep the line potential where it makes contact, the same or nearly the same as the potential difference of supply at A, a fair value of the current in such a feeder can be obtained by a consideration of its point of contact with the line and the number of cars between A and the end of the line. Clearly under the assumption of its maintaining the line potential difference the same as at A, and assuming the line and rail resistance, per unit length, constant, the feeder would supply current to one-half the cars between it and A if equally spaced out, and to all the cars beyond it to the end of the line. From this the current can be roughly judged, for if the cars be many, the average current per car could be taken. The drop of potential in the feeder itself has to be considered; if there are many feeders, and one portion of the plant is devoted to them, its potential must suit them all. The drop of potential difference in a feeder for a given current depends upon its resistance, and this, in turn, for a given length, depends upon the material of the feeder and its cross-

sectional area. In any case, if the potential difference between the ends of the feeder and the current in it be given, the rate of dissipation of energy in such feeder is also given. This, then, brings us to the continuing cost of the conductor.

Continuing Cost.—Lord Kelvin, in 1881, read a paper before the British Association on the "Economy of Conductors of Electricity," and there gave his law with regard to the same. It is this: That the interest on the first cost of the conductor and allowance for depreciation should be equal to the cost of energy actually dissipated in the conductor in a given time, say, per annum. The first cost of a conductor for an installation of a given size and type is easy to arrive at, by obtaining quotations from cable manufacturers, which prices, per mile say, will vary with the quality, the amount ordered, and the company supplying it. So that price lists can only be taken as a rough guide in estimating the cost. Then, again, there is the varying price of material. If a conductor be laid in a trench specially got out for it alone, it would seem only fair to charge such cost to the cable. But this does not always happen. If, for example, the cable be laid in earthenware ducts, there are probably other cables in the same duct, in which case the duct is really put down for a number of cables, and perhaps provision made for drawing in more. It is only experience and an examination of the given conditions which can enable an engineer to properly judge as to the first cost of his feeder. But, looking at the feeder alone, it is only for large sizes that one pays in almost direct proportion to the copper used. The curve *a*, in Fig. 20, gives the relation between the cost in shillings per yard per square inch cross-section of a lead-cased iron-sheathed cable, and the cross-section in square inches. Beyond about 0·2 square inch the curve is almost straight and gradually sloping towards the horizontal; that is to say, so far as the cost of this cable is concerned, it is more

nearly proportional to the volume of copper beyond 0·2 square inch than up to 0·2 square inch. This shows that it would be more economical, from this point of view, to put down this cable at about 0·2 or 0·3 square inch sectional area or greater. The curved portion, up to about 0·2, shows that the covering material is an important factor. The curve *b*, Fig. 20, gives the relation between the cost in pounds sterling per statute mile and square inches cross-

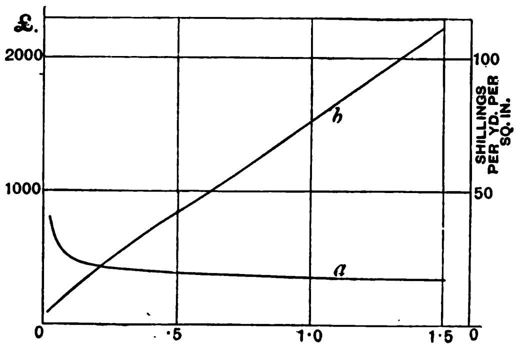


FIG. 20.

section, and this, although curving down towards the origin, would not pass through it.

It seems to be pretty well established that in traction work with efficient machinery a Board of Trade unit can be produced for 0·5 pence, or a little over. Taking this as a basis, and assuming the system as working 5000 hours per annum; one horse-power = 746 × 5000 = 3,730,000 watt-hrs. = 3730 Board of Trade units; therefore, the cost for one horse-power per annum is £7·6. Let us, however, assume that it actually costs £10 per annum. A feeder, 0·25 square inch cross-sectional area, weighs, say, 5000 pounds per statute mile. Suppose it is three miles long, then it weighs 6·7 tons. Taking the cost of the

cable at £550 per mile, if sheathed, the total cost equals £1650. The cost per ton is £246. Allow on this 10 per cent. for interest and depreciation, that is, £25 per annum. We ought, therefore, to waste one horse-power for every $\frac{10}{25}$ ton, that is, in this particular case we ought to waste 17 H.P. Take the resistance of the cable as 0·177 ohm per statute mile; the total resistance is 0·53 ohm. Then $\frac{C^2 \times 0·53}{746}$ should equal 17; whence C equals 150 amperes. The current density, then, is 600 amperes per square inch, and the drop of potential between the ends of this feeder is $150 \times 0·53 = 79$ volts. We see from this that the heating effect will not be injurious to the cable, and the drop of potential difference should suit the particular requirements in hand. The engineer should at least see that this law of economy is fairly fulfilled, always having due regard to heating and fall of potential. In laying down feeders in connection with the rail return, in order to comply with the Board of Trade limit of 7 volts drop in the rail, this law of continuing cost may have to be deviated from. For instance, if these feeders are connected together at the negative terminal of the machines, the long feeders may have more copper than would be dictated by Kelvin's Law, owing to the requisite diminished fall of potential difference, the short feeders complying with it. A way out of the difficulty would be to connect the long feeders together, and supply through them at greater potential difference by means of a separate machine, the short feeders being treated similarly. This leads to subdivision of plant. A further remedy would be the use of storage-cells, or another dynamo of small potential difference. Such cells or dynamo are sometimes known as "Boosters." When it is considered that the conductors might cost as much as 30 per cent. of the cost of the plant, one can realize how important it is to lay down copper to the greatest advantage. The actual laying of cables is a subject

beyond the scope of this work; but it may be mentioned that nowadays the best practice seems to be to run insulated cables either through porcelain or bitumen ducts, or through iron pipes.

These remarks on feeders refer to electric traction in general. The Author does not intend to enter into a full discussion as to the relative continuing and first cost of the other forms of feeders given in Figs. 18 and 19. The problem must be attacked in the same manner, but great experience and care are required to form a good judgment as to which is the best to adopt in a particular case.

Board of Trade Regulations with regard to Underground Feeders.—It is usual in tramway work to place feeders under the ground, and to continuously insulate them, although in some cases feeders are carried overhead and insulated on poles. In the case of railways, bare copper conductors, or ordinary rail sections can be used for feeders (see p. 78). An important regulation with regard to underground feeders is as follows:—"The insulation resistance of all continuously insulated cables used for lines, for insulated returns, *for feeders*, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of 10 megohms for a length of one mile. A test of the insulation of all such cables shall be made at least once in each month."* This is a very modest insulation resistance for a good class of cable, when one considers that as much as 2000 megohms per statute mile, after one minute's electrification, is a guaranteed insulation resistance when the cable is new. But it must be remembered that at any time during the life of a cable it must have 10 megohms per statute mile resistance, which is a very different matter. Of course this should be covered by the agreements which contractors enter into with regard to the maintenance of the cables.

Overhead Conductor.—It will be well to state here the

* See "Blackpool Corporation Tramways," February 11, 1897, Regulation XI., Appendix, p. 228.

principal regulations of the Board of Trade with regard to overhead insulated conductors. They are as follows: "The insulation of the line, and of the return when insulated, and of all feeders and other conductors shall be so maintained that the leakage current shall not exceed one hundredth of an ampere per mile of tramway. The leakage current shall be ascertained daily, before or after the hours of running, when the line is fully charged. If at any time it be found that the leakage current exceeds one-half an ampere per mile of tramway, the leak shall be localized and removed as soon as practicable, and the running of the cars shall be stopped, unless the leak is localized and removed within 24 hours; provided that where both line and return are placed within a conduit this regulation shall not apply." *

"The electrical pressure or difference of potential between any suspended conductors used in connection with the working of the tramways by electrical power and the earth, or between any two such suspended conductors, shall in no case exceed 500 volts continuous pressure." †

"The suspended conductors used in connection with the working of the tramways by electrical power shall be in no part at a less height from the surface of the street than 17 feet, and shall be securely attached to supports at intervals not exceeding 120 feet." ‡

"The line wire shall be divided up into sections not exceeding (except with the special approval of the Board of Trade) one quarter of a mile in length, between every two of which shall be inserted an emergency switch and a safety fuze or cut-out, constructed to act with a current exceeding the maximum working current by 50 per cent., which

* See "Blackpool Tramways," February 11, 1897, Regulation X., Appendix, p. 228.

† See Dublin Southern District Tramways, August 17, 1896, Regulation X., Appendix, p. 233.

‡ *Ibid*, Regulation XI., Appendix, p. 233.

apparatus shall be so enclosed as to be inaccessible to pedestrians." *

This is in conflict with Regulation No. 9 of the Board of Trade, dated July 24, 1896, and February 11, 1897, Appendix, p. 228, in which this distance is stated to be one-half mile, which is quite short enough.

We see from the regulations just quoted, that the insulation resistance of the line shall be so maintained that it shall not fall below 50,000 ohms per mile. This is on the assumption that the potential is 500 volts, and that if the resistance gets down to 1000 ohms per mile the fault is to be at once localized and removed. When one compares this with the 10 megohms for underground insulated conductors (see p. 58), it is evident that, if possible, the overhead conductor should be the only conductor. But this is not always possible, although there is a tendency towards heavier conductors. The question of sufficiency of copper depends upon the distance between the feeder-points and the number of cars to be supplied with energy between such points, for the drop of potential difference should not be excessive (see p. 30). A very common size of hard-drawn copper for overhead trolley lines is 0·324 inch diameter, or 0·0829 square inch cross-sectional area; but at Leeds Dr. Hopkinson has employed a copper conductor 0·4 of an inch diameter, having a cross-sectional area of 0·126 square inch, and 98 per cent. conductivity. One must bear in mind that a great increase in the size of conductor means also an increase in strength and cost of the poles and insulators. If the drop of potential between any two feeding-points is too severe with a given overhead conductor, the remedies are to increase its diameter, or to lay an underground insulated conductor placed in contact with the overhead conductor at intervals, so as to increase the effective cross-sectional area.

* See Dublin, etc., August 17, 1896, Regulation XII., Appendix, p. 233.

Suppose that we have two points in a conductor, α and β, and that the potential differences between each of these and the earth are maintained constant and equal. Let the resistance between α and β be 2R, let the distance $\alpha\,\beta$ be divided into $2n$ equal parts, and let there be $2n-1$ trains, making simultaneous contact with the conductor at each of the intermediate points, and each demanding the same current x. Then the whole current X entering this section at α is equal to $x(n-\frac{1}{2})$; also $\mathrm{R}=nr$, where r is the resistance of the conductor between two consecutive trains. Then the maximum drop in volts equals $x\left(\frac{n^2r}{2}\right)$ $=\frac{xn\mathrm{R}}{2}$, since $r=\frac{\mathrm{R}}{n}$. Of course these conditions are never realized, nor is it possible to get at the exact conditions in working. All one can do is to get a fair idea of what the maximum drop might be in a given case. As an example, let us examine the system at Dublin (see Fig. 21, and p. 190; also *Engineering*, June 5 and 12, 1896). In Fig. 21, A is the Ballsbridge Power House, B and C are sub-stations at Blackrock and Dalkey. Take the length of this line to be $7\frac{3}{4}$ miles; then the round trip equals $15\frac{1}{2}$ miles. Assume there are 20 cars and trailers on the line at the same time, and that the average velocity is $7\frac{3}{4}$ miles per hour; then the service would, under these conditions, equal six minutes. The average distance between the trains equals about 1360 yards. There are two trolley wires, each 0·0829 square inch section, and between the sub-stations at Blackrock and Dalkey an underground insulated conductor of 0·1435 square inches section connected to the trolley wire at eight intermediate points. Assume, then, we have a continuous copper conductor between these two points, B and C, Fig. 21, of 0·309 square inch section. Take the distance to be $4\frac{1}{2}$ miles. The resistance of such a length is, say, 0·664 ohm. Assume that there are 10 cars, each with trailers on the two lines

between these points, equally spaced out, and that each car is taking 20 amperes; 20 amperes at 500 volts corresponds to about 13 H.P., and is taken to be the *average*

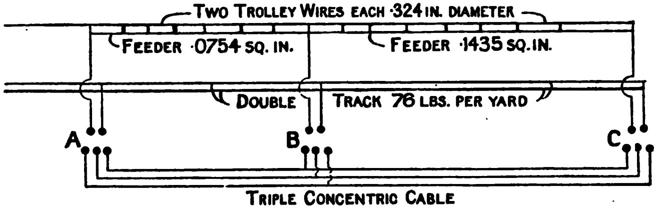


FIG. 21.

power per car. At an average speed of seven miles per hour the work required per mile is about $1\frac{1}{2}$ Board of Trade units per car and trailer. Then the drop in volts $= \frac{xnR}{2} = \frac{20 \times 6 \times 0·332}{2} = 20$ nearly. [Or if the trains are sufficiently numerous, the drop in volts reduces to $\frac{XR}{2}$, which is then quite near enough, since the exact conditions are not known.] This is the drop of potential in the report alluded to. Take the maximum drop in rail. The resistance neglecting joints is about 0·00984 ohm per mile,* since the rail has 76 lbs. weight per yard; 4·5 miles have resistance 0·0444 ohm. Then $\frac{xnR}{2} = 1·33$ volts.

Fig. 22 gives a diagram of the system of conductors put down by Dr. Hopkinson at Leeds. The total length of the line is about 12,300 yards. There is no underground conductor in parallel with the trolley wire; therefore we have only the drop in the wire itself to consider. Take the points B′ and C′ in Fig. 22, distant about 3250 yards. Assume that there are three cars between these points, and that the potential difference at these points is maintained

* See page 76.

constant at 500 volts. The trolley wire has a diameter of 0·4 of an inch and a cross-section of 0·126 square inch; 3250 yards have a resistance of 0·668 ohm. In this case

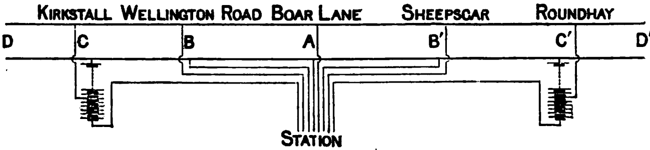


FIG. 22.

$n = 2$, and assume $x = 20$ since the cars are few; this is greater than the average and less than the maximum current. The drop is 6·7 volts. In actual work the potential difference at the feeding-points is not, of course, absolutely constant as has been assumed. It must vary to some extent. But these two instances are given simply to show the sort of figure one might obtain in actual working.

Appliances used in Erection of Conductor.—The methods and materials used in the erection of overhead wires is a subject of great practical importance, and about which much has been written. There are a variety of ways of suspending the overhead conductor; for instance, in narrow streets it can be supported by an insulator fixed to a span wire bridging across the opposite walls, or the span wire may be supported by poles on each side of the track. This latter method is adopted in many places where plenty of width is available. Again, the conductor or conductors can be supported on insulators by means of poles, which can be placed either in the middle or at the side of the roadway. When placed in the middle of the road, the track being double, such poles can be fixed in an island of pavement with a pillar at each end to protect it from injury. Such poles can also be used for the erection of arc lamps, and so serve a double purpose; this is done at Dover and

also at Leeds (see Fig. 29). At the present time steel tubular poles are universally adopted, these being securely fixed in concrete foundations. A great deal of time and money has been spent upon obtaining efficient means for insulating the conductor from the bracket arm or span wire, and the devices used are somewhat numerous. The great point in such apparatus is the insulating material; this should be hard, durable, and protected as much as possible from moisture. In all such devices this material is in compression, for insulation materials can be made which will stand great compressive stresses. Well-known insulation materials are the Ætna and Medbury. One of these insulators is shown in Fig. 23. The clamp to which the

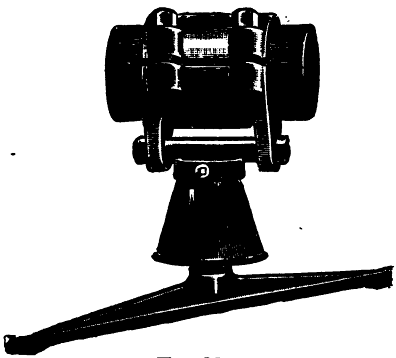


FIG. 23.

conductor is soldered is screwed on to a bolt covered with hard insulating material. The bolt again is supported by a casting in such manner that the material round the underneath side of the bolt head is in compression. This is the general method adopted in suspending a conductor. A part of the same casting consists of a hood, which protects the insulation material from rain and moisture.

Various methods are adopted for supporting the overhead

wire. This is almost always circular, and is soldered into a support as shown in Fig. 24. This method, although mechanically good, would seem to disturb the smooth running of the trolley wheel at high speeds. Another

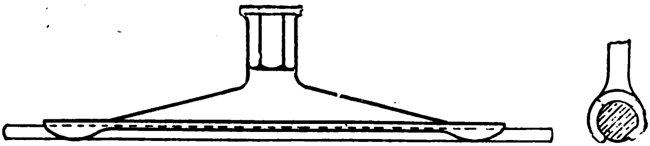


FIG. 24.

section for the wire, as shown in Fig. 25, has been tried, the support being clamped to the upper portion. This gives smooth running for the trolley-wheel, but an objection to this section is that the wire is liable to kink. The circular pattern can be supported by means of a clamp, which grips the wire by two grooves, milled out as shown

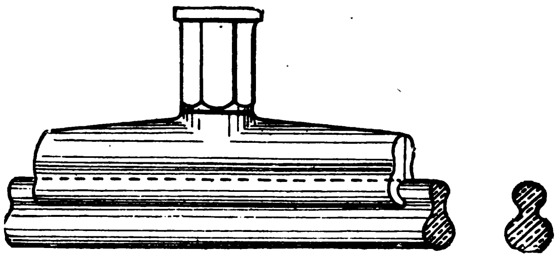


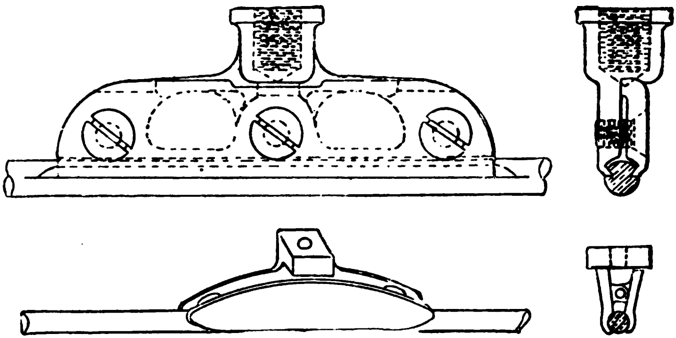
FIG. 25.

in Fig. 26. The circular conductor can also be gripped as shown in Fig. 27.

A V-shaped casting, usually called a "Frog," is used for branch circuits, and guides the trolley-wheel in the desired direction.

The Board of Trade regulation (see *ante*, p. 59; and Appendix, p. 228) states that the line wire shall be divided

up into sections. This is generally carried out at a pole by means of a section insulator. The wire at this point is broken, and the space between the two ends, of about one foot, filled up with a piece of hard wood or fibre in such manner that the trolley runs along the same. The two ends are carried by conductors down the pole to a street box



Figs. 26 and 27.

containing fuzes, and, if necessary, the feeder is connected to the line at one of these points. In this manner, by withdrawing the fuze at any two adjacent boxes, the line in between them can be isolated and submitted to test. Such a section insulator is shown in Fig. 28. With a single

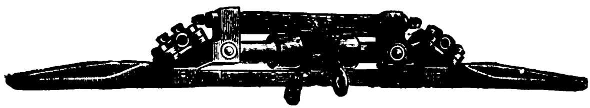


Fig. 28.

trolley on the car it is obvious that the circuit must be broken at these points. The motorman knows when this would occur, and breaks the circuit just before reaching such point, making it immediately after. In this manner the flash does not occur at the insulator. This breaking

of contact between the trolley wheel and the line is considered by some to be objectionable ; in such cases, storage-cells are usually employed on the car for lighting purposes (see p. 215). It is usual to erect guard-wires where necessary to prevent telephone and telegraph wires from falling on the over-head conductor.

Lightning Arresters.—The subject of lightning arresters is of importance since the line wires are liable to be struck. There are several good arresters for use in traction work. The "Ajax," the British Thomson-Houston, and the Westinghouse or Wurts arresters are largely used, and are placed on each car, on the posts and in the central station.

The "Ajax" arrester consists of a series of specially constructed fuzes, arranged in such manner that one after the other is automatically brought into operative position by the action of the discharge current as it consumes each fuze in turn. The fuze itself consists of two insulated wires placed with their ends overlapping, but not touching, the distance between the parallel portions of the ends being secured by sealing such ends into a plug of insulating material at each end of a small glass tube. When the lightning strikes, the current leaps across the gap and burns out the wire. This allows a small metal ball to fall into contact with the end of the next fuze lower down, thereby leaving it in position for the next discharge. The general arrangement is such that a fresh set of fuzes can be quickly inserted.

The well-known magnetic blow-out principle is used in the Thomson-Houston lightning arrester. It provides a ready path for the lightning across a small air-gap, and the line current immediately tends to flow to earth ; but this is prevented by making it traverse a coil which energises an electro-magnet, the field of which immediately extinguishes the arc formed. It is obvious that such an arrester provides very great protection, since a quick succession of lightning flashes can be as quickly dealt with.

The Wurts non-Arcing lightning arrester is very simple and effective. The discharge is caused to pass between two brass electrodes, separated by half an inch, over narrow grooves burned in a block of lignum vitæ. This differs from the old telegraph arrester, which consists of a series of opposing points on two metal blocks with a short air-space between them, in that the discharge leaps from block to block over the charred surface, and the conducting vapours, which are necessary to the formation and maintenance of a dynamo arc, are suppressed by the cover which fits tightly over the metal electrodes. The well-known Wurts arrester, with metal cylinders, is used in the case of alternate current systems.

Sag in Wires.—We see from the Board of Trade Regulations (see Appendix, p. 233; Regulation XI.) that the distance between the ground and any point of the conductor shall be at least 17 feet, and that the distance between the supports is not to exceed 120 feet. This naturally introduces the subject of sag in wires, for the minimum distance between the earth and the line will be midway between the supports, if these be horizontal, at the highest temperature. The question of sag in wires is an important one, and has been worked out from theoretical considerations, which have been proved to be all that is required in practice. The true form of the curve is the catenary, but it is usual in calculating tensions for small sag, to suppose it a parabola without introducing serious error.

The overhead line has of course to encounter very varying atmospheric conditions, such as strong winds, temperature variations, and the deposit of snow and ice. Wind-pressure brings great stresses to bear upon the insulators and poles. Variation of temperature produces changes in the tensile stress of the conductor itself, thereby varying the sag on account of expansion and contraction, whilst snow and ice add to the weight per unit length, and therefore to the stress on insulators, etc. It is important for a given safe

stress in the conductor at insulator to see that the required dip or sag has a given value at a certain temperature. For instance, if the line be put up in summer when the temperature is high, the sag must be such that in winter, or at the lowest temperature, the conductor will not be overstrained. From this we see that the overground distance does not give the actual length to the conductor. Allowance must be made for sag. If S be the actual length of wire between the two supports in feet, T the stress in the conductor at the insulator in pounds per square inch, BS the breaking stress in pounds per square inch, D the dip or sag in feet, that is, it is the difference between the heights of the conductor at the insulator and the lowest point, A the distance between the poles in feet, and w the weight in pounds per foot of the conductor, then we have the following equations:—$D = \frac{A^2 w}{8T}$; $S = A + \frac{8D^2}{3A}$ and, assuming a factor of safety of 4, $T = \frac{BS}{4}$.

In a given case assume that A = 120 feet, D = $1\frac{1}{2}$ feet at its maximum, BS = 60,000 lbs. per square inch, which is a very fair figure for hard drawn copper. Take 0·4 inch as the diameter of the trolley wire, that is 0·126 square inch section. Since a cubic inch of copper weighs 0·32 lb., the weight of 12 inches of wire = 3·84 times the cross-sectional area in square inches; hence the weight per foot = 3·84 × 0·126 = 0·484 lb.; then T = 581; this corresponds to 4,600 lbs. per square inch.

We have still to take into account wind pressure, for when this is severe the resultant force will be that due to gravity and such wind pressure. A very high wind exerts a pressure of perhaps 30 or 40 lbs. per square foot; so that the force due to wind, say per foot length of the conductor, will be some function of this pressure and the diameter of the wire. The surface of the wire is cylindrical instead of flat, and, therefore, a correction is due for this.

Take it that the pressure on the wire is 0·6 of what it would be if the surface exposed to the wind were flat. Then the maximum force due to wind pressure per foot length $= 0{\cdot}6 \times \frac{y}{12} \times$ the maximum pressure per square foot due to wind pressure; where y is the diameter of the wire in inches. This is equal to 0·8 lb. in the case we are considering, as against 0·484 lb. due to gravity. The resultant due to these two causes combined is equal to $\sqrt{0{\cdot}64 + 0{\cdot}23} = 0{\cdot}94$ lb. Inserting this in equation $T = \frac{A^2 w}{8D}$, for w, instead of 0·484 we have double the tension in the wire at the insulator, or, say, 1200 lbs., which gives a factor of safety of about 6.

We have next to consider the contraction of the wire when at its lowest temperature. This will bring greater tensile stress to bear upon it, since it diminishes the dip D. Take the co-efficient of expansion of copper at 0·00001 per degree Fahrenheit, and allow for a fall of 30° Fahr., say on 50° Fahr., the temperature at which the wire is to be erected with $1\frac{1}{2}$ foot dip. The contraction on 120 feet is 0·036 foot. The length of wire at 50° Fahr. is 120·05 feet; then 120·014 is the length of the wire at 20° Fahr., the lowest assumed temperature. $D = \sqrt{\frac{3A(S - A)}{8}} = 0{\cdot}8$ foot. $T = 2000$ lbs. if we assume $w = 0{\cdot}94$; the factor of safety $= 3{\cdot}6$. Similarly one could find the dip and stress in a conductor at any other temperature.

The Supporting Pole for Overhead Conductor.—The pole has to support two wires on a double track, and has also to withstand wind pressure on its own surface. The test which sample poles, chosen from a batch by the engineer, have to pass is severe, and proves whether the pole will telescope or loosen at the joints when let fall end foremost three times from a distance of six feet, and whether

it will not take a permanent set when fixed horizontally at one end, and a weight is applied at or near the other end.

Two grades of poles, manufactured by Messrs. Russell, are used at Leeds; each has an overall length of 31 feet made up as follows. The smaller grade is made up of two sections, the bottom section consisting of 7-inch pipe 17 feet long and $\frac{1}{2}$ inch thick, and the top section consisting of 6-inch pipe tapering to $4\frac{1}{4}$ inches, 14 feet long and $\frac{3}{8}$ inch thick, the weight of the pole being about 920 lbs. The larger grade is also made up of two sections, the bottom section being 8-inch pipe 17 feet long and $\frac{5}{8}$ inch thick, and the top section tapering from 7 inches to $4\frac{7}{8}$ inches, 14 feet long and $\frac{5}{8}$ inch thick; its weight being about 1300 lbs.

The sections of each pole are shrunk together hot under pressure so as to make perfect joints, with 18-inch insertion for each joint, which is then covered by a cast-iron ring.

The test for these poles provides that the pole shall be fixed horizontally, one support being at the butt end and the other six feet therefrom. The small pole is to be loaded with 700 lbs. at a point 18 inches from the top end, and shall not be deflected more than six inches at the extreme end. A weight of 1200 lbs. shall then be applied at the same position, and the permanent deflection shall not exceed half an inch. The large size pole is to be similarly tested, the weights being 1000 and 1700 lbs. respectively, the temporary and permanent deflections not to exceed six inches and half an inch respectively.

Fig. 29 shows one of these poles, which is also arranged for carrying a Brockie-Pell 10-ampere arc lamp. There are 40 of these arc lamps attached to the poles at Leeds; they are arranged in four circuits of 10 in series, and are supplied from the tramway feeder at a potential of from 480 to 500 volts, one end of each circuit being connected to the rail return. These arc lamps are in the centre of the town, and the circuits are so arranged that, in the event

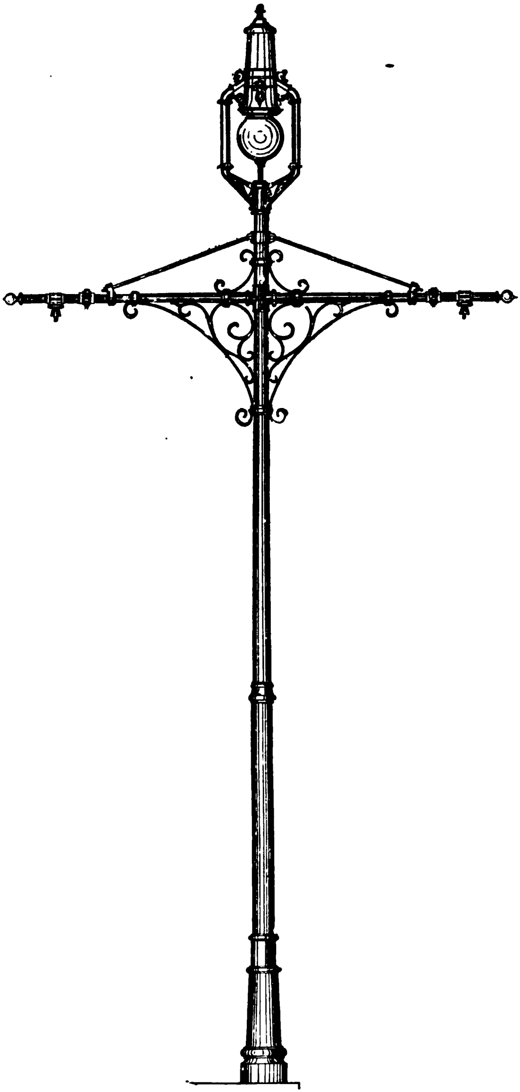


Fig. 29.

of one giving out, alternate lamps will still be left burning. A single trolley wire as described, with insulators, would cost roughly £200 per mile, and the poles for two wires would cost roughly £1200 per mile. In the case of span wires the supports must be such as to allow for their sag, since the conductor at the insulator must be at the required height above the ground in order that its lowest point is not less than 17 feet from the ground.

Overground Conductor.—Probably the first method employed to convey energy electrically to cars was a steel conductor near the surface of the ground, supported at intervals on insulators of glass or porcelain. Sir William Siemens read a paper on "Electrical Transmission and Storage of Power" before the Institution of Civil Engineers in 1883, in which he mentions such a method being used in Berlin by his brother in 1879, the line being 900 yards long and the gauge 2 feet. He also described the Portrush line which he was then constructing, in which a similar device was used. In this case it consists of a T girder placed at the side of the rails, against which rub the conductor or conductors fixed to the car and attached to one pole of the motor on the car, the other pole being connected to the rail which forms the return. Table V. on next page gives particulars of the early lines in Great Britain, and is taken from "Electric Railways," by Dr. E. Hopkinson,* It shows the early use of this form of conductor.

Notable instances of the use of a channel steel conductor are the City and South London Railway and the Liverpool Overhead Railway. A requirement of such a conductor is that it must be strong in addition to its conducting properties. Table VI. is taken from a paper by Dr. J. Hopkinson on the "Magnetization of Iron," † for the purpose of showing how the electrical conductivity of iron and steel varies according to the composition.

* See *Proceedings Institution of Civil Engineers*, 1893, vol. cxii. p. 230.

† See *Transactions Royal Society*, 1885.

TABLE V.

Date of opening.		Miles.	System.	
1883	Portrush & Giant's Causeway ...	8	Side conductor ...	Water power
1883	Brighton Beach ...	1	Rails	Gas engine
1885	Bessbrook & Newry Tramway ...	3¼	Central conductor	Water power
1886	Ryde Pier ...	½	Side conductor ...	Gas engine
1886	Blackpool ...	2	Conduit	Steam
1889	Carstairs	1¼	Side conductors ...	Water power
1890	Birmingham ...	3	Accumulator ...	—
1891	Southend Pier ...	¾	Central conductor	Steam
1891	Guernsey	2¾	Overhead conductor	,,
1891	Leeds	3¼	,, ,,	,,
1893	South Staffordshire	7½	,, ,,	,,

TABLE VI.

Material.	Temper.	Total carbon.	Manganese.	Sulphur.	Silicon.	Phosphorous.		Specific resistance in 10^{-6} ohms.
Wrought iron	Annealed	—	—	—	—	—	—	13·78
Bessemer mild steel	—	0·015	0·2	0·3	none	0·040	—	10·5
Whitworth mild steel	Annealed	0·090	0·153	0·016	none	0·042	—	10·8
,, ,,	,,	0·890	0·165	0·005	0·081	0·019	—	15·59
,, ,,	Oil hardened	0·890	0·165	0·005	0·081	0·019	—	16·95
Manganese steel ...	As forged	0·674	4·73	0·023	0·608	0·078	—	53·68
,, ,, ..	Annealed	0·674	—	—	—	—	—	39·28
,, ,,	Oil hardened	0·674	—	—	—	—	—	55·56
Chrome steel	As forged	0·687	0·028	0·020	0·134	0·043	Chromium 1·195	17·91
,, ,, ...	Annealed	0·687	—	—	—	—	—	18·49
,, ,, ...	Oil hardened	0·687	—	—	—	—	—	30·35
Tungsten steel ...	As forged	1·357	0·036	none	0·043	0·047	Tungsten 4·649	22·49
,, ,, ...	Annealed	1·357	—	—	—	—	—	22·50
,, ,, ...	Hardened in cold water	1·357	—	—	—	—	—	22·74
Grey cast-iron	—	3·45	0·173	0·012	2·04	0·151	Graphitic carbon 2·06	114·0
Spiegel eisen	—	4·51	7·97	trace	0·502	0·128		105·2

The great variation of the conductivity shows how important it is to have regard to the composition of the material to be employed, but first cost must also be borne in mind. The weight per yard is, on the assumption of equal specific gravity, the quantity which determines the sectional area, and also the cost for a given form or shape of section. Other things being equal it is of course best to choose that material which has the highest conductivity.

The specific resistance of copper is about $1\cdot6 \times 10^{-6}$ ohm. Compare this with those in Table VI. Bessemer and Whitworth mild steel, the latter annealed, are the best, with a specific resistance of 10·5 and $10\cdot8 \times 10^{-6}$ ohms respectively. We see that increasing the carbon from 0·09 to 0·89 in the Whitworth steel increases the resistance 50 per cent.; whereas oil-hardening the latter specimen does not make so much difference—an increase, in fact, from 15·6 to 16·9. Of the other steels given chrome is the best, with 17·9 as forged and 18·5 annealed. Wrought iron is better than any of these, with 13·8. The worst of the irons or steels given is undoubtedly manganese steel, with 4·73 per cent. of manganese; for even annealed its specific resistance is 39·3. This subject has been discussed by Dr. E. Hopkinson before the Institution of Civil Engineers, 1887, and the steel used by him on the Bessbrook and Newry Tramway was manufactured by the Darlington Steel and Iron Co., and is stated to have the following composition: carbon 0·09, silicon 0·02, manganese 0·63 per cent., and the specific resistance is $12\cdot1 \times 10^{-6}$ ohms. The weight per foot of the conductor is 4·33 lbs., and the cross-sectional area 1·367 square inch. The cost delivered at the wharf at Newry was £7 10*s.* per ton, whilst copper at the time was £84 per ton. This shows in favour of steel, when taking cost and conductivity into account for a given weight, in the ratio of $\frac{84}{7\cdot5} \times \frac{1\cdot6}{12\cdot1} = \frac{3}{2}$.

Let w = the weight in pounds per cubic inch of the

steel employed = 0·28, say; let A = the cross-sectional area in square inches; and let ρ = the specific resistance in ohms. Then $36 \times A \times w$ = the weight in pounds per yard. Therefore $A = \frac{\text{lbs. per yard}}{36 \times w}$. Then the resistance per mile of such a conductor $= \frac{\rho \times 91{\cdot}44 \times 1760 \times 36 \times w}{\text{lbs. per yard} \times 6{\cdot}45}$, or, taking w at 0·28, and ρ at 12×10^{-6}, which is an average value, the resistance per mile $= \frac{3{\cdot}02}{\text{lbs. per yard}}$ ohms. This is, perhaps, a useful way of expressing the relation; and of course, when possible, one should always get the specific resistance of the material to be employed. We have taken herein no account of joints,* which, as we shall see, are of very great importance in traction work. Further, the two conductors in a double track are probably cross-bonded, so that, in using the above formula, one must divide again by 2 to get the resistance per mile of the two conductors in parallel; or, in using this formula for tramway rails, one should divide by 2 for single and 4 for double track.

By eliminating silicon and slightly diminishing the carbon in the mild steel used on the City and South London Railway, although the manganese was somewhat greater, a specific resistance of $10{\cdot}5 \times 10^{-6}$ ohms was obtained.† The conductor (Fig. 2, p. 18) is supported on glass insulators, and weighs 10 lbs. per lineal yard. The shoe for collecting energy is shown in Figs. 1 and 2. The leakage of the electric system, consisting of dynamos, feeders, and working conductor, is stated to be generally about one-half of an ampere, and rarely exceeds one ampere when tested at 500 volts. If we assume this to be all in the conductor and equally distributed along its length, since the track has a length of say 3·1 miles, the resistance per mile is 3120 ohms.

Fig. 30 gives a view of the insulator and conductor

* For Electrical Resistance of Joints, see p. 84.

† See *Journal of the Institution of Civil Engineers*, vol. cxii. p. 215.

used on the Liverpool Overhead Railway, and has been taken from *Inst. C.E.*, vol. cxvii. pt. iii. The conductor is of steel, rolled in lengths of $32\frac{1}{2}$ feet, has a cross-sectional area of 4 square inches, and weighs 40 lbs. per lineal yard. It is supported every $7\frac{1}{2}$ feet (except at the joints, where the insulators are $2\frac{1}{2}$ feet apart) on porcelain insulators designed for oil; but this was not used, inasmuch as the leakage was considered low enough without the oil.

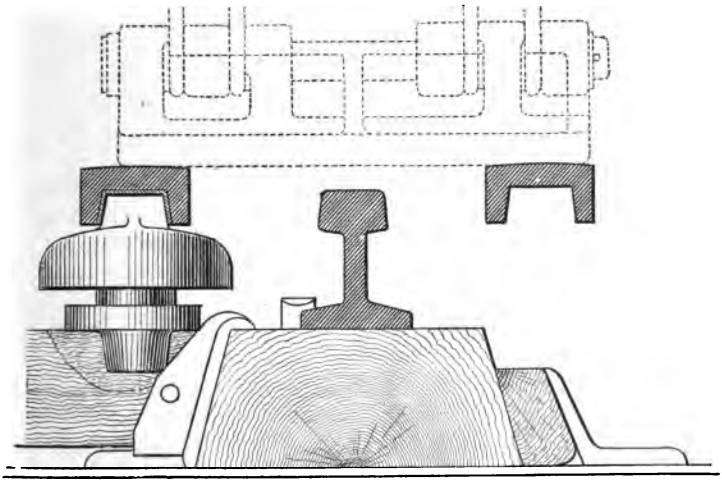


FIG. 30.

There are no feeders, and the return circuit is through the rails. These latter weigh 56 lbs. per yard.

This figure also shows how the conductor is arranged at a crossing. It is broken and bent parallel to the main rails, and since it is three-quarters of an inch above these, the iron shoe attached to the car can bridge across, and so clear the rail return. Neither the composition nor the specific resistance of this steel conductor is given. If it is mild steel, it might have a resistance per mile, neglecting joints,

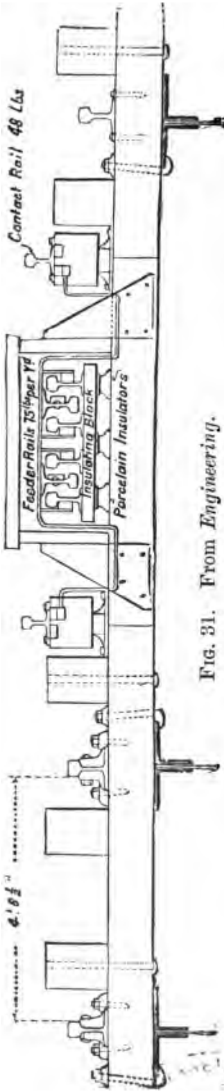


FIG. 31. From *Engineering*.

of 0·075 ohm, or one-half of this for the two conductors in parallel. The leakage current is stated to be two or three amperes. Take it at 2·5; take the length of the track at six miles; then the resistance per mile = 1200 ohms for the double track. This and the 3120 ohms per mile of the City and South London Railway are very low as compared with the 50,000 ohms per mile laid down by the Board of Trade for tramways, and the minimum of 1000 ohms per mile, for which the cars may be stopped running (see Regulation X., Appendix, p. 228). But it must be remembered that there is no traffic over these lines other than the trains.

On the Chicago elevated railway, where there are 12 miles in operation, the girder rail is used for the conductor, having 48 lbs. per yard, and a conductivity equal to a copper rod one inch in diameter. The area of this conductor might be 4·76 square inches; that is, the specific resistance = $9 \cdot 7 \times 10^{-6}$ ohms, which would indicate a very good quality of steel. Steel rails are used for feeders on this railway, and Fig. 31 gives a section of the roadway, showing the rails, the insulated overground conductor, and the steel feeders, which are placed in the centre of the way and protected as shown.

Fig. 32 illustrates the shoe used to collect energy by rubbing against the insulated rail conductor. It will be

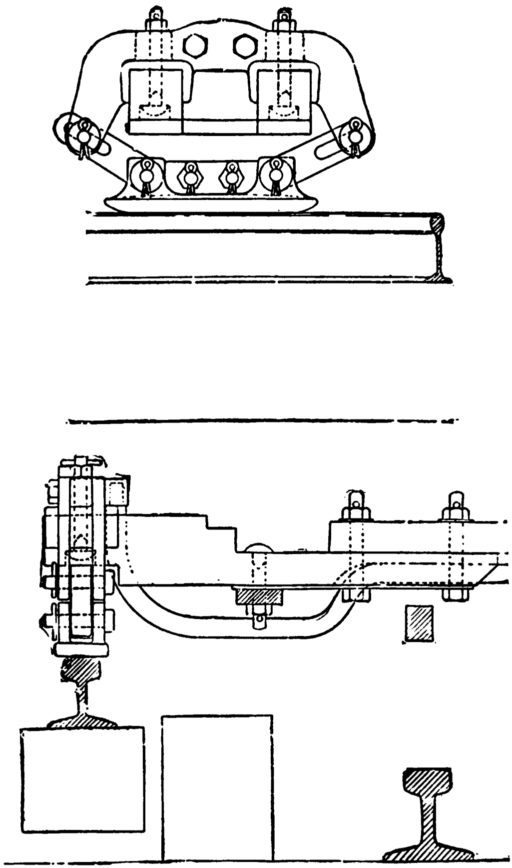


FIG. 32. From *Engineering*.

seen from the figure that the shoe is free to move up or down, and overhangs the car.

CHAPTER IV.

THE TRACK AND ROLLING-STOCK.

General Remarks.—The history and development of the construction of rails for tramways is well set forth in D. K. Clark's "Tramways," to which the reader is referred for this and other valuable information. At the present time, for electrical tramway work the girder rail is almost universally used, its weight per yard depending, in the first instance, upon the strength required and other mechanical considerations; and, in the second place, upon its electrical properties, since in electrical tramways the rail is also used as a conductor. The engineer has, therefore, to look at this matter from another point of view. Fig. 33 gives a representative section of roadway now met with in tramway

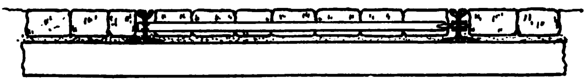


FIG. 33.

work. The rails for each track are connected by tie-bars, and generally laid on concrete, granite setts being laid in between and on each side of the track, the rest of the surface being the ordinary roadway material. The spaces between the setts and the rails are generally filled up with asphalte. Wood blocks are also used instead of granite. Irrespective of any electrical considerations, the price per mile of an ordinary tramway line is of interest. According

to Clark, the following are examples of the cost per mile of single track, without the bonding necessary when the rails are used as electrical conductors :—

	£
Vignoles rails, 42 lbs. per yard	1823
Paving for same	2275
Total	4098
Kincaird girder rails (Fig. 33), 78 lbs. per yard	1831
Paving for same	1641
Total	3472

At Liverpool in 1892, where there were $47\frac{1}{2}$ miles of tramway on the Lever System, the cost of maintenance of the ten years up to 1892 is under one per cent. per annum, on a basis of £6000 per mile, which price is for a first-class permanent way on concrete foundations, into which the rails are secured. The wear for 100,000 tons of traffic per annum is stated as being about 0·015 inch, or 0·0086 of the original weight, which was 40 lbs. per yard.

Gauge.—The gauge on tramways varies very much. Where plenty of width of roadway is available, it is generally 4 feet $8\frac{1}{2}$ inches, but varies from $2\frac{1}{2}$ feet to 5 feet. At Dublin the gauge is 5 feet $2\frac{3}{16}$ inches, concrete bed, four tie-bars per rail. At Leeds the gauge is 4 feet $8\frac{1}{2}$ inches concrete bed, with granite setts and asphalte. At Walsall the gauge is 3 feet 6 inches. On the Continent the metre gauge is very popular. The subject of gauge has especial interest at the present time on account of the activity in the construction of light railways consequent upon the passing of the Light Railways Act, 1896 (see p. 5). The standard gauge of 4 feet $8\frac{1}{2}$ inches should be adopted where practicable, and when a "light railway" is intended to feed into a main line. At the same time a narrower gauge would seem imperative in the case of narrow roads, and to save expense when taking the line across fields. Few roads

can spare the width of way necessary to take the standard gauge, and the first cost of a tramway capable of carrying loaded cars as on a railway would often be prohibitive. It is, nevertheless, important that some uniform narrow gauge should be adopted, such, for instance, as 2 feet 6 inches. The weight of rail per yard varies within wide limits from 40 or 50 lbs. per yard to over 100. The tendency now is towards heavy sections.

Gradients.—Gradients are in many instances severe; for example, at Montreal 1 in 8 and 1 in 10 are common. These have an influence upon the power supplied, unless means be provided for returning the energy to the system from the car when descending (see p. 136). Some of the gradients in Bristol are 1 in 15, whilst in Dublin 1 in 20 is met with. Then, again, the curves are often sharp; and this introduces a greater tractive resistance.

The Rail as a Return Conductor.—In Great Britain the engineer, when considering the line as a return conductor, must comply with certain regulations of the Board of Trade. See Appendix, p. 226, regulations 3 to 8 inclusive, under date February 11, 1897.

Regulation 7 settles to some extent the size of rail to be put down, since it gives the limit as to drop of potential difference. Assume, for instance, that the rail weighs 100 lbs. per yard, which is a comparatively heavy section. Then it might, for a double track, when acting as an electrical conductor, and if properly jointed, have a resistance of 0·0075 ohm per mile. Suppose the line were 10 miles long, and the average current 200 amperes, then clearly the Board of Trade Regulation would be exceeded. In order to comply with this regulation, it is clear that, for a given system—and each one must be treated individually—the cross-sectional area, or weight in pounds per yard for a given quality, is an important quantity; for if this be too small, another conductor must be laid in parallel with the track, and connected with it at intervals not exceeding 100

feet if such conductor be uninsulated. See Regulation 4, Appendix, p. 226. For resistance of rails, see p. 76.

We have already discussed the influence of feeders on the distribution of currents in the rails (pp. 53, 54). If the line is used as a return, it must be preserved as a good continuous conductor. The ordinary tramway track, although perfectly sound at the joints mechanically, becomes at

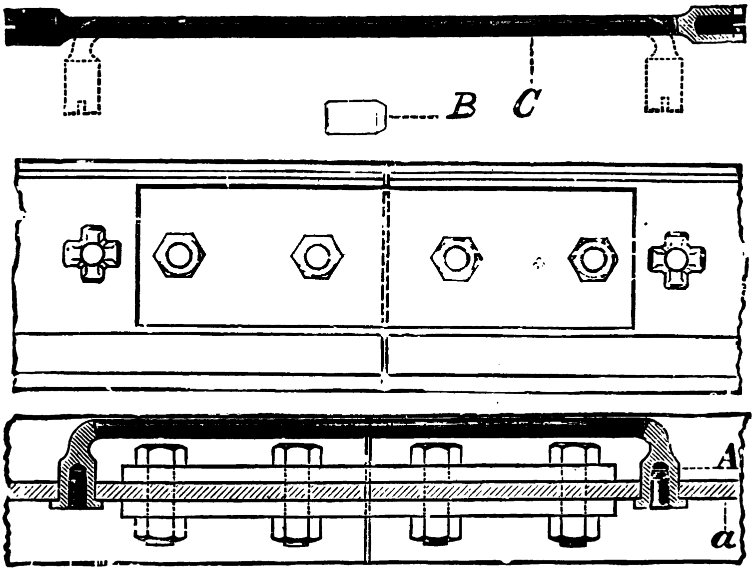


FIG. 34.

these points a bad conductor in time, owing to rust. Many devices for getting over this difficulty have been adopted. One of these, and perhaps the oldest, is to bridge across the joints with a copper conductor. At the present time the Chicago rail bond (Fig. 34) is very largely used. It consists of a copper conductor C which is bent at each end, the ends A being expanded into freshly drilled holes in the web

a of each rail by means of a drift-pin B driven into a hole in the end of the bond. Such a device has been well tried, and is very much used at the present time.* As many as two, or even three, such bonds are used per joint, according to the size of the rail. This is a costly operation, and forms a fairly large item in the cost of a tramway line. It may cost £300 per mile of double track with two bonds per joint.

The great cause of difficulty is, no doubt, the up and down motion of the rail joints when traversed by cars. This works the bonds loose, and bad connections may ensue. There are various other forms of rail bond besides that just mentioned. The Edison-Brown plastic rail bond has much to recommend it, if after long trial it proves efficient. This device (Fig. 35) makes use of the fish-plate itself as the intermediate conductor. Between the web of each of the two rails to be jointed and the fish-plate is placed an amalgam, the contact surfaces being thoroughly cleaned and treated with a solid alloy, which silvers them and keeps them free from rust. An elastic cork, with a hole through it, is placed against the web of the rail, and supports the amalgam before placing and fixing the fish plate in position. The current then passes from one rail through the amalgam, through the fish-plate, through the other piece of amalgam to the next rail. It is claimed that in the case of a 9-inch rail, the bond will carry 1500 amperes with a drop of potential of 0·03 volt. Another method of applying the amalgam is to drill a hole through the top of the rail into the fish-plate, or through the bottom of the fish-plate into the bottom of the rail, in either case filling with amalgam and sealing up with a metal plug. There is another method which, if it gives a perfectly good result, electrically speaking, will be of very great value. It is to cast-weld the joints, thus making a continuous rail. Ordinary welded joints, butt to butt, have been tried on

* The electrical resistance of a newly made joint is stated to be from 0·000017 to 0·000034 ohm. C. Billberg, *Electrician*, Sept. 24, 1897.

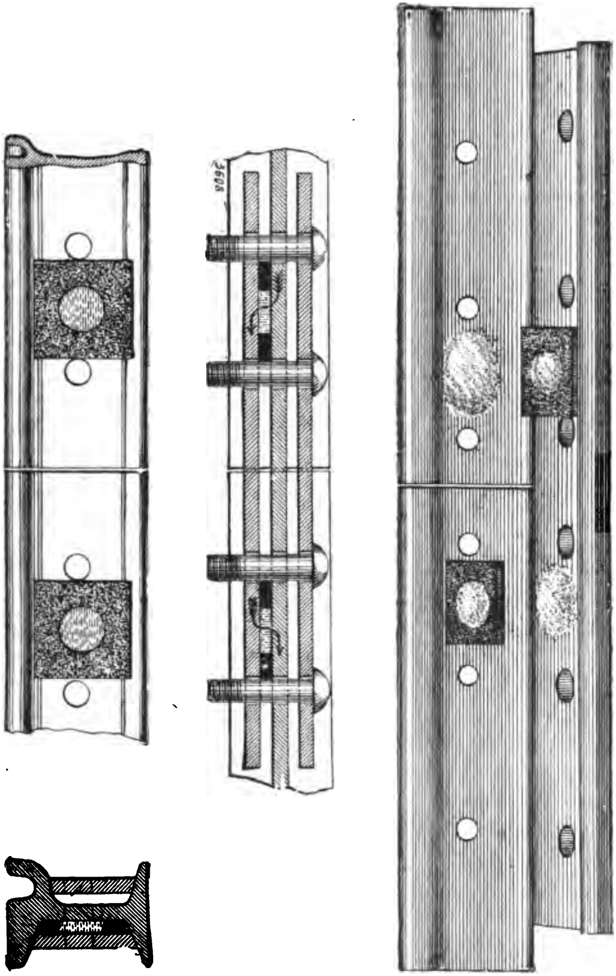


FIG. 35.

$6\frac{1}{2}$ miles at St. Louis, 5 miles at Cleveland, and 32 miles at Brooklyn, the welding being carried out by electricity. St. Louis had 3 miles of cast-welded joints; and in Chicago there are, it is reported, about 12,000 such joints. Molten metal is poured into a mould round the end of the rails, and thus makes a bond, joining them. It seems that sometimes a sliding action sets in on expansion and contraction, which, from an electrical standpoint, is bad. This process is carried out in cold weather preferably, so that when hot weather steps in the rails expand and do not so much tend to sever the joints. Only time and experience will sift out the best from the many types.

Bonding in Great Britain is of very great moment, on account of the Board of Trade regulations (see Appendix); but with proper care there is no reason why these should not be more than complied with. In America the matter is different, since the regulations are not so stringent. At the same time bonding is necessary from the point of view of economy. Since the rules in Great Britain are so severe, it follows that the bonding of rails has been brought more prominently to the front, and has exercised, and will exercise, a great influence upon the question of feeders.

Rolling Stock.—The whole subject of rolling stock is of great importance, and cannot be dealt with exhaustively in a work of this magnitude. We illustrate in Fig. 36 a Leeds motor-car, which may be taken to represent the ordinary tramcar with overhead seats. Twenty-five such cars are supplied at Leeds, each capable of seating 50 passengers. The car bodies are mounted upon Peckham standard cantilever extension trucks, and were constructed for the contractors, Messrs. Greenwood & Batley, of Leeds, by Messrs. G. F. Milnes & Co. The length of wheel base is 6 feet. Each car is supplied with two motors, having single reduction gear, and operated on the series-parallel control system. The cars are supplied with two meters—one for recording the ampere-hours, the other for recording


J. W. COURTENAY. TRAMWAY ADVERTISING CONTRACTOR
ROUNDHAY & KIRKSTALL.
14
14
LEEDS CITY TRAMWAYS.
Fig. 36.

the maximum current. Each car is wired for 10 – 16 C.P. lamps, connected five in series between the trolley wheel and rail. The trolley is of the swivelling-arm type, fixed to a standard on the car roof, the springs being such that a pressure of about 28 lbs. is exerted between the trolley wheel and wire.

Leeds Tramcar Test.—The test imposed upon the contractors by Dr. J. Hopkinson, in connection with the Leeds tramcars, is of interest. The test to which the motor-cars must be subjected, and which they must pass, is that each one shall stop for five seconds every five minutes, and shall complete the round trip, loaded with three tons, in one hour fifty minutes, with a consumption of not more than 28 ampere-hours, and that the current required shall never exceed 50 amperes, the supply being maintained at a potential of not less than 480 volts.

Taking the line to be about 7 miles long, corresponds to an average velocity of about 7½ miles per hour, and an expenditure of about one Board of Trade unit per mile.

The Board of Trade regulations with regard to tramcars and trailer cars are dealt with generally on pages 5 and 6. They are given in full in the Appendix.

The discussion as to whether large cars are to be used, or smaller ones with trailers, is a very broad one. But a very important thing to note is the Board of Trade regulations with regard to attendants on cars and trailers. In Regulation III., relating to the Dublin Southern District Tramway (see Appendix, p. 231), it is stated that each trailing car must carry a brake-man as well as a conductor. This rule is of great importance apart from the fact that this brakeman may or may not apply his brake in keeping with the motor-man on the leading car. For particulars of the Dublin cars, see p. 189.

When it is considered that the cost of coal, oil, water, and wages at the generating station, other than wages for repairs, may be less than a halfpenny per car mile run,

whereas the cost of wages of car-driver and conductor may be more than twopence per car mile run, one can understand how important it is to have as few conductors and drivers as possible. According to the above regulation, we see that two men are required on the trailer as well as on the motor-car, and this already large expense is doubled if we add the trailer. On the other hand, such an arrangement of cars and trailers makes the system much more flexible, since the trailers need only be used when the traffic is great. At the same time the motors must be able to cope with both loads. The long cars take more time to empty, and do not give so much flexibility to the system. We find trailers at Dublin and on many other lines.

The discussion as to whether locomotives and coaches, as on the South London Railway, or motor-cars, as on the Liverpool Overhead Railway, should be used depends upon the size of the trains and conditions as to head room, and the engineer himself. In subways where room is limited, the locomotive would seem to be the better solution; on the other hand, with long trains, if each car has its own motors, and all the motors have to be controlled by one conductor, the switching arrangement becomes complicated. The Chicago Elevated Railway has motor-cars similar to the Liverpool Overhead Railway. This line resembles the elevated portions of London railways, and was opened in 1895. The cars are 40 feet long, and mounted on steel framing with bogies at each end. There are 55 motor-coaches and 100 trail coaches, the proposed length of line when complete being 18 miles, of which 12 are in operation. The cross-section of the roadway is given in Fig. 29.*

The under-truck and bogie are structures upon which the car body itself is mounted, and which have received careful attention from the makers. Such structures must be properly braced to resist deformation; they must be strong and light, and carry the car body with a minimum

* See *Engineering*, January 10, 1896.

of vibration. The axle-boxes must be dust-proof and self-lubricating, and the wheels fitted with an adjustable brake, the shoes for which must be easily got at for removal. The construction of trucks has been carried to great perfection, and there are several well-known builders. A Peckham truck is illustrated in Fig. 53. Fig. 67 shows a

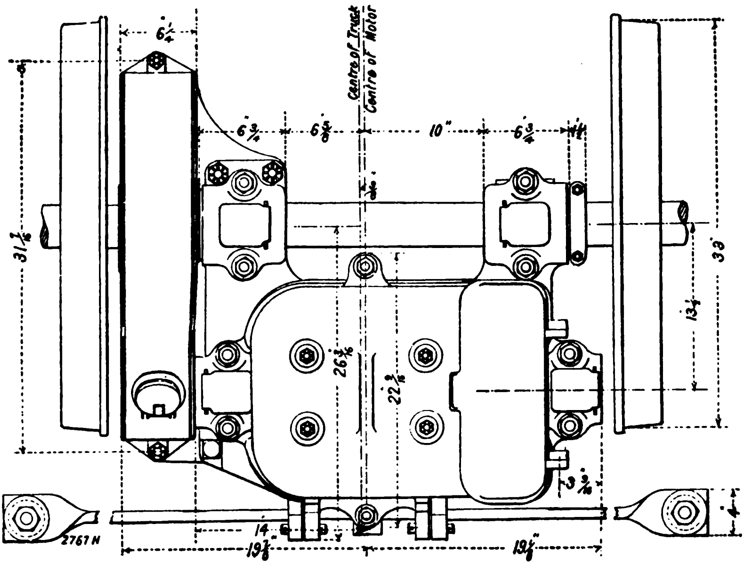


Fig. 37. From *Engineering*.

single motor mounted on an under-truck for an ordinary tramcar.

The suspension of the motor on the truck has been well thought out. Fig. 37 gives a plan of a General Electric 800 motor. One end of the motor is supported by the car axle itself, which works in bearings formed by extensions of the shell. The other end of the motor is usually carried by a lug cast on the shell of the motor, such lug fitting

into a hole in a transverse bar, supported from the under-truck by means of springs. Another method is to support this end of the motor from two lugs carried by longitudinal side bars also supported by springs on each side of the motor. The former method is more used, and is well shown in Fig. 37. This plan shows the gear-case, which protects the spur-wheel and pinion from dust and dirt, and gives details of the cast-steel shell of the motor.

Brakes.—The subject of brakes has been touched upon at p. 6. It may be mentioned that Mr. Baylor, in his recent paper before the Institution of Electrical Engineers,* describes and illustrates a very ingenious brake, which utilizes the motor when converted into a generator and driven as such by the momentum of the car. It does not bring excessive stress to bear upon the armature, since the armature conductors need only carry their normal current and operate the brake, which may be arranged to be very powerful. By means of an inter-connection between motor-car and trailer, such a brake could be operated by the motor-man on the motor-car, thus dispensing with the brake-man on trailer, and making the operation much more secure, since the motor-man can see at once what to do, and time is lost if he has to signal to the man behind.

A usual provision is to short-circuit the motor armature in extreme cases, but this brings very severe stresses to bear upon the armature and gearing.

Brakes are also worked by compressed air, as on the City and South London Railway.

The Board of Trade regulations with regard to brakes are given in I*a*., II*a*., Appendix, pp. 231, 232.

Tractive Resistance on Tramway Lines.—A great many experiments have been made to determine the tractive resistance in, say, pounds per ton of the gross load on the driving-wheels of tramway lines. The results, as one would expect, depend very much upon the state of the rails. In

* See *Proceedings*, vol. xxvi.

dirty weather, when the rails get filled up with mud, a greater resistance is introduced than in fine weather, when the grooves may be clear. Experiments made by Mr. Holt at Leeds show a tractive resistance of about 22 lbs. per ton of gross load, at an average of 6 miles per hour on a flat groove rail in fair condition. He also found that the initial pull exerted might be from 100 to 160 lbs. per ton. On the Nottingham tramways Mr. Perrett found that the tractive force varies very much with the weather; he obtained on a straight and level track, when clear, 25 lbs. per ton; and on a curve 22 feet radius, up a gradient of 1 in 130, the force rose to 94 lbs. per ton. To start a car on the level in dirty weather, he found a pull of 66 lbs. per ton necessary; whereas on the curve and gradient mentioned, this rose to 130 lbs. per ton.

Reckenzaun states in the *Electrician*, May, 1890, that the mean tractive force in tramway work may be anything from 30 to 50 lbs. per ton; it is seldom below 20 on level roads. This is very different to an ordinary railway, where 15 lbs. per ton is a fair figure to take.

CHAPTER V.

THE SLOTTED CONDUIT SYSTEM.

General Remarks.—Probably the avoidance of an overhead conductor, and the examples set by cable tramways, led the early workers in electric traction to experiment with what is generally termed the "slotted conduit system." This consists of an underground conduit, generally of an oval section, running the whole length of the line, with a narrow opening on the surface to permit of a plough or metal conductor passing down from the tram-car into the conduit. The conductor or conductors from which electrical energy has to be taken are supported on insulators fixed to the walls of the conduit, and rubbing contact is made between them and the collector. In this manner the car can, as it travels along, receive energy in the form of electricity, with the same facility that energy is received from the overhead-conductor, only that now the live conductor is under the surface of the roadway. It can be easily understood that such a system as this is expensive to construct, especially in towns or cities where there are already gas and water pipes and electric-light mains. Further than this, the whole system has to be properly drained, since water would, if deep enough to come in contact with the live conductor, cause very serious trouble; and provision must be made for cleaning out the conduit. This is generally carried out by having sumps at intervals along the line. The earliest attempts at electric traction in streets where this system was tried, showed how

important it was to have the conduit of ample dimensions and sufficient strength to keep the slot from closing in owing to the severe stresses due to frost and ordinary traffic. Holroyd Smith in England, and Bently-Knight in America, were early in the field with slotted conduits, and at the present time there are several examples in practice. Crosby and Bell, in their second edition (1896) of "Electric Railways," state that "the Bently-Knight roads in this country" (meaning America) "have now been totally abandoned after long and costly experiments; and there is to-day no conduit road in operation in America, unless we except an experimental one in Chicago." On the other hand, Dawson, in his "Electric Railways and Tramways," 1897, p. 471, states, in connection with the "Love" system, that "it was put into use at Washington on March 3, 1893, and has been continually at work since;" so that authorities differ. But in any case there are examples in England, America, and on the Continent, of slotted conduits. This system has advantages and disadvantages. Once the conduit is constructed, both the positive and negative mains can be supported on either side, and in this way electrolytic action on water and gas-pipes can be avoided, since the rails need not be used as a return circuit. There are examples in which the positive and negative mains are supported on insulators in the conduit, and also in which only the positive main is so carried, the rails themselves serving as the return; the former, of course, is the better to adopt. Naturally the strength required in the conductor demands a larger cross-sectional area than one meets with in overhead wires, and this is an advantage from an electrical point of view, since greater conductivity is secured.

Electric Osmosis.—The same effects due to electrical osmosis observed in the ordinary electric lighting system of conduits are also observed with this system; that is to say, if the insulation resistance be measured, the

positive conductor is found to be more highly insulated than the negative, and on reversing the poles this effect is also reversed, which proves that it is not casual. A simple experiment carried out in the Siemens Laboratory, King's College, London, under the direction of Dr. J. Hopkinson, by Messrs. Highfield and Adlard, illustrates this well-known effect. An ordinary insulator of porcelain, as used in electric light conduits, with slots for the reception of copper strip conductors, was placed in a tray of water, the water just touching the bottom of the insulator. Two bare copper conductors placed in the slots were connected to the poles of a battery of 56 storage-cells, and the leakage current between the positive and water and the negative and water measured, means being provided to reverse the poles of the battery when desired. The following figures show the character of the results:—

Time	10·55 a.m.	12·10 p.m.	1·0 p.m.
Positive leakage current	51 ...	14 ...	14
Negative leakage current	40 ...	75 ...	74

The currents are stated in arbitrary units. On reversing the poles the effect was reversed. This effect may be explained as follows. Suppose two vessels containing water to communicate by a cotton wick, and two electrodes, differing much in potential, to dip into the two vessels; then it is found that water passes over continuously from the vessel into which the positive electrode dips to that into which the negative electrode dips. The action of bare conductors is the same upon a larger scale. The main source for moisture is from the walls and floor of the culvert; this moisture will constantly creep over the porcelain insulators towards the negative conductor, but will creep away from the positive conductor, drying the neighbourhood of the latter and improving its insulation.

It is reported by Dawson* that at Washington the insulation resistance of two miles of conduit varies from

* See "Electric Railways and Tramways," p. 481.

8300 to 27,600 ohms on the positive side, and from 400 to 910 on the negative side, for varying states of weather, which shows the same effect.

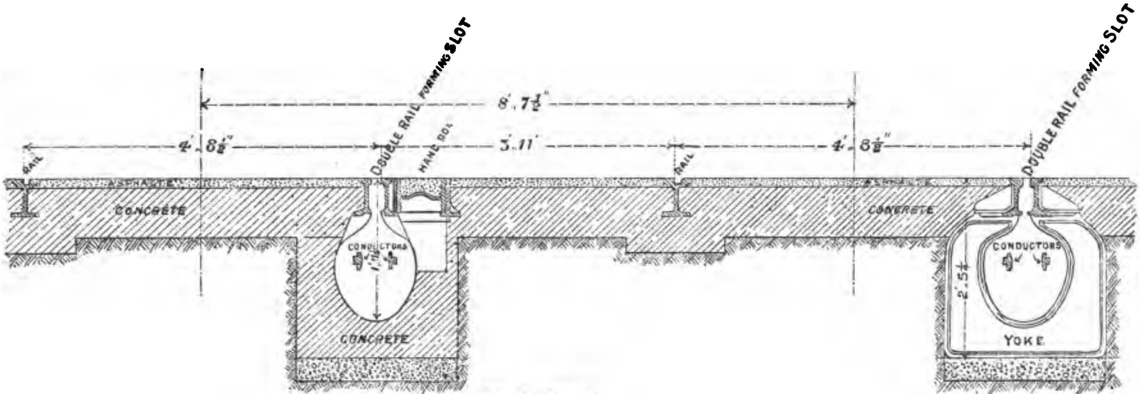
For the Board of Trade regulations with regard to conduits, see Appendix, pp. 229, 230.

Objections.—The great objection to the slotted conduit is its cost, which must of course vary with the locality in which it is placed. It is just in crowded thoroughfares, where opposition to the overhead conductor is great, that so many other interests have to be considered; and this is just the place where the slotted conduit system is likely to be useful, for in the suburbs the overhead trolley can be used without much opposition. Other matters which are said to militate against the use of the slotted conduit are the danger and inconvenience caused by the slot itself, and the serious and prolonged interference with the streets both during construction and repairs.

Descriptive Matter.—The following short descriptions of some of the more important conduit lines at present in use will serve to show the different methods adopted.

Budapest.—One of the most important examples of the slotted conduit system is that of this city, which has a population of 500,000. The streets are generally very wide, and the trams run on either side, leaving the centre free for ordinary traffic. There are a few steep gradients, the steepest being about 1 in 18, but generally the streets are flat. The paving is generally granite, but asphalte is used, and the rails used are of a special section, each one being practically a double girder of about 170 lbs. per yard. The gauge is throughout 4 feet $8\frac{1}{2}$ inches, and when the conversion of horse lines is finished there will be about 44 miles, as follows :—

		Length of line in miles.		Miles of track.
Electric underground	...	2·3	...	4·7
Electric conduit	...	14·5	...	30·0
Electric overhead	...	26·7	...	54·0

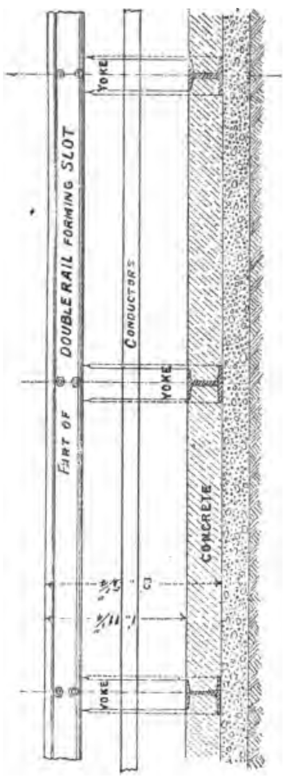


CROSS SECTION.

FIG. 38.

H

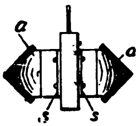
The Budapest tramways are owned by two companies, the Street Tramways Company and the Electrical Town Line Company founded by Messrs. Siemens and Halske, who laid the first electric line in 1887. Storage-cell cars have been tried, but were not considered a success. It is stated that all the horse lines are to be converted into electric within the next four years. Figs. 38 and 39 give details of the slotted conduit at Berlin, and will serve to illustrate that of Budapest, except that at Budapest both rails are of the double girder type. The underground conduit is about 22 inches deep, and is under one rail, the slot between the rails varying from $1\frac{1}{2}$ to 2 inches at curves. At intervals of 66 to 130 yards there are manholes, which give access for cleaning and repairing; and there are two handholes midway between the manholes. The two conductors, one on each side, are carefully insulated, and form the going and return circuits. There is, therefore, no return by the rails. A collector attached to the car passes down through the slots and rubs against the live conductors. Fig. 40 gives the collector in plan and sectional



LONGITUDINAL SECTION.
FIG. 39.

elevation.* It will be seen that the rubbing contacts, *a*, *a*, are mounted on springs, S, S, arranged in such manner that the blocks are pressed outwards, so as to make good and efficient contact with the conductors, which are of L section.

The cost per mile varies from £4600 to a maximum of £6900, against which the overhead is placed at about £3000 when using the rails as a return. The maximum voltage is 500. The cars are arranged to seat 50 persons inside and out; some are fitted with one and some with two motors. The weights are: for a one-motor-car 6·75 tons, and for a two-motor-car 8·3 tons, each of which has a daily mileage of 186. The fares vary from $1\frac{1}{2}$*d.* to 3*d.* The maximum speed allowed is 15 miles per hour, but this



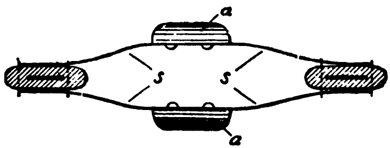


FIG. 40.

varies with the street traffic. The service is from 5 to $3\frac{1}{2}$ minutes, and the tramway runs for 11 hours per diem. It is reported that on exceptional occasions the line has been stopped by snow.

Berlin.—Electric cars have been running in this city since May, 1896, and when complete there will be more than 150 miles of overhead conductors alone. The length of overhead is 8 miles, and of conduit $5\frac{1}{4}$ miles. Although the overhead line is allowed in some streets in the city, the police object to it in the centre, and to meet this the company is adopting conduit. Meanwhile it has been decided to run storage cell cars. There is conduit on three routes, mostly constructed by Siemens and Halske,

* See H. Smith, *Journal Northern Society of Electrical Engineers* 1895.

the Union Company having laid a short length. The cross section of the roadway is shown in Fig. 38, and a longitudinal section through the slot in Fig. 39. The combination of overhead and conduit seems to work well; the change from one to the other can be made while the car is running and is scarcely perceptible. It is stated that the cost per mile overhead is £2400 as against £6450 for slotted conduit, not including concrete work. The voltage is 500, and the power is supplied by another company at about 1*d.* per unit. There are about 50 motor-cars, each capable of seating 34 passengers, weighing about 7 tons empty, and $9\frac{3}{4}$ tons full. The fares vary from 1*d.* for from $1\frac{1}{2}$ to 2 miles, and $3\frac{1}{2}$*d.* for about 7 miles; and the maximum speed is $12\frac{1}{2}$ miles per hour. The service is from 4 to 10 minutes. The objections to the slotted conduit system are its first cost, length of time occupied in construction and repairs, and dirt and moisture in the conduit interfering with the working.

New York Electric Conduit Tramways.—In this system the conduit is laid in the centre of the track, and contains two conductors, one on each side of the conduit. These form the going and return conductors of the system, so that the rails are not used for electrical purposes. Fig. 41 gives details of the insulator for supporting the T conductor, the other half of the conduit being the same as shown in the figure. The general features of this conduit are very good, and represent the best practice. The lower part of the framework up to the line MN is one casting. Firmly bolted to the frame is a cast-iron cap, G, which supports the insulator and working conductor. The insulator, P, is of porcelain, and is cemented into the cap G by means of concrete, C, the distance piece, J, preserving a sufficient space for the cement. The insulators are arranged at intervals of 14 feet along the conduit, and a handhole over each gives immediate access. Manholes are placed every 200 feet along the line, having the dimensions 4 feet

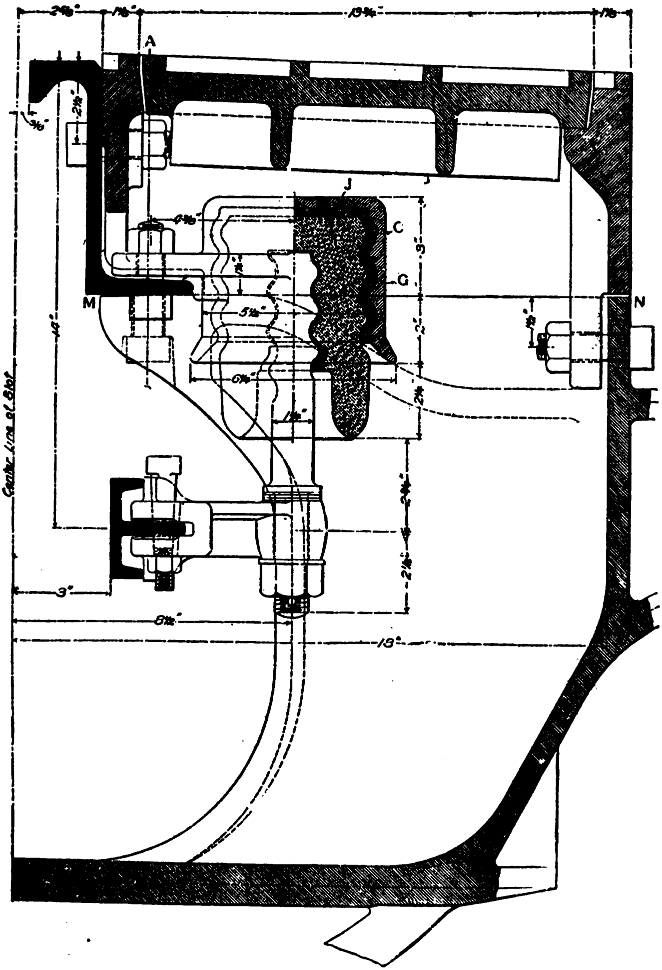


FIG. 41.

10 inches deep, 4 feet long, and 17 feet 2 inches wide. The working conductors are 6 ins. apart, and each one weighs 21 lbs. to the yard. The slot rails weigh 57 lbs. per yard, and the track rails 107. The latter are in 30 feet lengths and 9 inches deep. This system has been in operation in New York city on Manhattan Island, and has proved so satisfactory that the company have decided to employ these designs on about 40 miles of track.

Brussels.—The earliest electric line in this city has been in use since May, 1894. The overhead and conduit systems are used, and are being equipped by the Union Company of Berlin, under a guarantee as to the cost of the working of the line. The guarantee was $2\frac{1}{2}d.$ per car per mile; and as to the overhead lines the cost came out at less than this, so that the company were relieved of their responsibility before the term of guarantee had expired.

With regard to the conduit line it is stated that the cost was about £19,000 per mile of double line including everything, and at this price it was handed over to the company ready for service. In January, 1897, about seven miles of conduit line were in course of construction. The cars and trailers are arranged to carry from 32 to 34 passengers, but frequently 60 or 70 persons are carried on the car and trailer, with the result that the speed is reduced. On the better class of line the cars are divided into first and second class, the first class being provided with cushioned seats, and in the second only bent wood is used. There are two motors on each car, and these are usually 15 and 25 H.P. The weight of the car is $6\frac{1}{4}$ tons empty, and each car runs about 80 miles per day. The cars cost £670 each. At present there are 28 motor-cars; this number is to be increased to 100 during 1897. As is usual, the cars take up passengers at any point on the line; but definite stopping-places are arranged from 200 to 300 yards apart, and only stop there

to set down. The speed is nominally about $7\frac{1}{2}$ miles per hour, but this is often exceeded. It is stated that the company's receipts are 70 per cent. more on the electric lines than on those worked by horses. The service is frequent, being every $3\frac{1}{2}$ minutes on some days, and every 7 minutes on others; but next year, it is stated, there are to be 18 cars per hour.

Blackpool.—The electric traction scheme in Blackpool, which is of the conduit type, is due to Mr. Holroyd Smith, and the conditions of working are necessarily very varied on account of this being a seaside resort. As a matter of fact, the population in winter is perhaps about 30,000, whereas in summer it is said to be as much as 120,000. Special difficulties have to be contended with on account of the effects of sea-water and sand blowing into the conduit. The line runs along the promenade or sea-front, which is generally a good width. The steepest gradient is about 1 in 50, and the sharpest curve has a radius of about 40 feet. The rails are of the girder type, and weigh about 92 to 97 lbs. per yard. The slot and conduit are in the centre between the rails. The electric tramway is two miles in length; the gauge is 4 feet $8\frac{1}{2}$ inches. The slot is about $\frac{5}{8}$ inch wide, which is much narrower than that already cited at Budapest. The motor-cars are of two sizes. There are four large ones, each with two 8-H.P. motors, and carry 82 persons, and weigh 11 tons 14 cwts. The small cars are ten in number, each has one 4-H.P. motor, and carries 54 passengers; the weight of the small cars is $4\frac{1}{2}$ tons. The large cars are 36 feet long, and cost about £800, £360 of this being for the car body. The fares on the electric route are 2*d.* in summer, for the whole journey of about two miles, and 1*d.* in winter. No less fares than those just mentioned are taken. The voltage is 250. No accumulators are used either in the station or on the cars. The speed of the cars is eight miles per hour, the Board of Trade limit; and the service is almost constant

in summer, whereas in winter it is at intervals of ten minutes.

A distinctive feature of Mr. Holroyd Smith's system is that he employs worm-wheel instead of ordinary spur-gearing on the motor-cars. Some years ago Mr. Reckenzaun found that the efficiency of this form of gearing increases with the speed, and was from 84 to 95 per cent.; the ratio of reduction was 8 to 1, and speed of motor varied from 300 to 900 revolutions per minute.

The collector is shown in Fig. 42, and the following is Mr. Smith's description of it. It consists of three main parts, one centre-piece, C, and two clearing ploughs, PP, for enabling it to run in either direction. One of the elements of success is the employment of flexible collectors flexibly connected to the car, and automatically detachable therefrom. For this purpose the two ploughs are joined to the centre-piece, either by a tempered steel strip, S, or a hinged wrought-iron plate, H. The steel plates forming the ploughs are held by cast-iron cheeks placed at an angle, and extending downwards a little past the bottom of the steel troughs forming the surface of the channel; their upper ends terminate in a hook or finger curved backwards. The hooks received the "snap loop" of the hauling ropes, which are attached to the front and rear of the car. These snap links are strong enough for ordinary work, but should an absolute block occur, the break and the collector is left behind, while the car, by its momentum, still travels forward, and the snap link of the trailing rope slips off the hook of the rear plough. The centre-piece consists of a cast-iron clamp holding a plate of strong brass, which is thoroughly insulated and protected by hardened steel guards where it passes the channel slot. The bottom of the plate is bared of insulating material, and has attached to it a flapper or wing, held outward by a spring so as to maintain contact with the conductor-rod. The current is taken from the collector by a short length

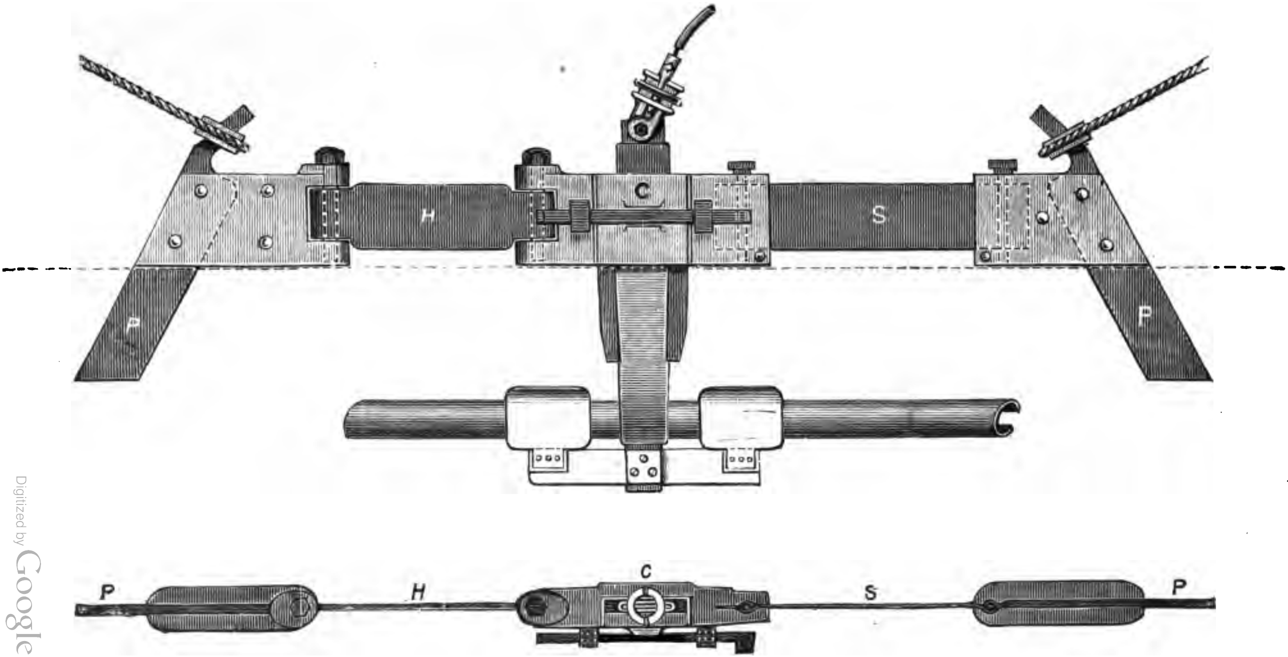


FIG. 42.

of insulated wire, provided at either end with a clip, one end attached to a terminal under the car, the other to the upper end of the brass plate that passes through the iron clamps. In case of the collector breaking away these clips readily let go.

The Author is indebted to Mr. Smith for information respecting his new system of underground conduits, which has received the approval of the Demonstration Française des Ponts et Chaussees of Paris. The channels are formed under the rails, and, in the case of a double tram-line, lie next to the inter-space. The underground conduit is large enough for a man to get along the whole length of the line, and in that way repairs can be effected without taking up the roadway. Also the great depth of the conduit allows of dirt and water being kept far enough away from the rails. The channels are supported on transverse H girders let into the walls of the conduit, and any dirt which may get in between the slot must fall to the bottom of the conduit, and can easily be swept away. At intervals along the line there are switches by means of which the sections of the conductor can be insulated, and a live conductor is carried on a porcelain insulator inside the conduit, and is attached at different points to the rubbing conductors. The Author has no data with regard to the probable first cost of this system, so that he cannot compare it with the other methods already given.

Combined Cable and Electric Traction.—An allied system has been proposed by Mr. Scott (see *Journal of the Inst. of E. E.*, vol. xxvi.), in which a cable tramway is worked by means of electric motors in order to diminish the friction due to running a cable round corners, and to supply power to cars when ascending very steep gradients, but the Author is not aware of this system having been put into operation.

Other Slotted Conduit Systems.—The Author has not the space to discuss all the proposed slotted conduit systems.

It is not necessary to remark that many ways of solving this problem are possible. For instance, the Lachmann and "Simplex" systems present novel features (see *Electrician*, July 2, 1897, and *The Railway World*, April, 1897).

CHAPTER VI.

THE SURFACE-CONTACT SYSTEM.

General.—In this system of supplying electrical energy for traction purposes, a series of surface-conductors or buttons are arranged in the line of the track, and project slightly above the ground, perhaps $\frac{3}{8}$ of an inch. These conductors are charged by automatic apparatus under the ground only when a car is over them, and are intended to become electrically "dead" when the car has passed on its journey. Fixed underneath the car are sliding conductors, which make contact with these buttons and collect the current for propelling the car, and also actuate the apparatus under the ground for connecting the surface-conductors to the supply main. This system has advantages and disadvantages.

The advantages are, of course, that no overhead wires are required; further than this, by charging only a portion of the conductors, the leakage is very much diminished, and in this way economy of power is secured. The disadvantages are that the automatic apparatus may possibly fail to act, in which case the surface-conductors might be left charged, thereby making it very dangerous to foot passengers, and horses might be killed. This is rendered very improbable by the use of a trailing piece which touches the buttons in turn, and disables the apparatus in the event of one being left alive. For the purpose of classification the Author divides this system into three groups.

First.—The system in which insulated sections are

employed, these being charged or rendered alive by a mechanical contrivance. These appliances can be actuated by other means than the car, and this makes the system dangerous. So far as the Author is aware the first system patented is that of Ayrton and Perry in 1881. In this system the flange of the wheel on the car is made to depress a lever just before entering a section, such depression connecting that section to the source of electric supply, which can be an insulated feeder running parallel with the track. Having entered the section, the car is propelled by the current passing through this, but the flange immediately presses another lever, which disconnects the section just left, and makes it dead. Thus contact is broken between it and the supply feeder.

Second.—The system in which the sections are made alive by the lifting up of the conductor, which is placed in a closed conduit underneath the ground, such lifting being brought about by a magnet attached to the car. Lineff's 1888 patent describes a system in which an insulated flexible conductor, in the form of a strip, is connected to the source of supply, and rests normally on the bottom of a closed underground conduit. Attached to the car is a long electro-magnet, with poles near to the surface, and this, by virtue of its magnetism, sucks up the flexible conductor underneath, and establishes contact with the section to be made alive. This system has been tried on a length of experimental line in London, and reported upon by Mr. Kapp.*

Diatto.—In this system a series of electro-magnets, M_1, M_2, M_3, M_4, M_5, in Fig. 43, are mounted upon an iron skate, E, which is long enough to touch two consecutive contacts, a_1, a_2. These contacts slightly project above the ground level, and serve to transmit electrical current to the motor M, when connected to the insulated supply-feeder C. Underneath each contact, a_1, a_2, etc., an iron

* See *Electrician*, Sept. 12, 1890.

bolt floats in mercury in a vertical cylinder, the mercury being connected through the metal cylinder permanently to the feeder, C. When the skate, carrying the electro-magnets M_1, M_2, etc., which are excited by a shunt circuit across the motor, comes over a surface-contact, the magnet nearest it attracts the iron bolt b_1, lifting it into contact with a_1, and electrical connection is thereby established. After the car has passed on its journey, the bolt b_1 drops

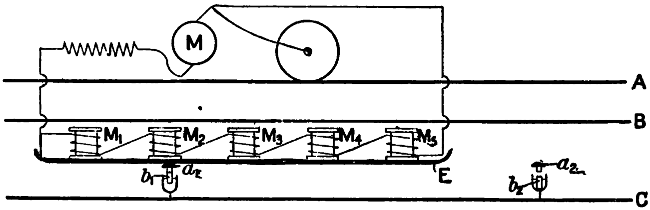


FIG. 43.

and severs contact. This system, according to Meréchal, is being tried at Toure and Saint Nazaire.

Wheless, McLaughlin, and others have patents for systems in which a magnet on the car lifts an armature under the ground, thereby actuating a switch which places a surface-contact in connection with a supply-feeder.

Third.—The system in which sections are made alive solely by electro-magnetic means, thereby necessitating the connection between the car, and suitable contacts only for the passage of the electric current. A battery carried on the car generally supplies current for starting such connections, but in some cases the line current also does this.

The objects to be attained may be briefly summarized as follows: First, absolute safety as regards disconnecting the surface conductors from the supply-feeder after the car ceases to be over them. Second, the reliability of obtaining a supply of current, especially at high speeds. Third,

leakage to be guarded against, as this might operate the electro-magnets, rendering the surface-contacts alive, and thereby occasioning great danger to pedestrians and horses. Fourth, facility for getting at the automatic apparatus in case of failure. Fifth, means of propelling the car over short distances independently of the switch apparatus. Sixth, to remove complications at points and crossings.

This system would seem to offer the best solution to the problem. The manner in which different inventors have dealt with this matter will be best understood by describing their individual systems. The following will serve to illustrate several different methods of attacking the same problem, and there are no doubt others.

Hopkinson, 1882.—Dr. J. Hopkinson was, so far as the

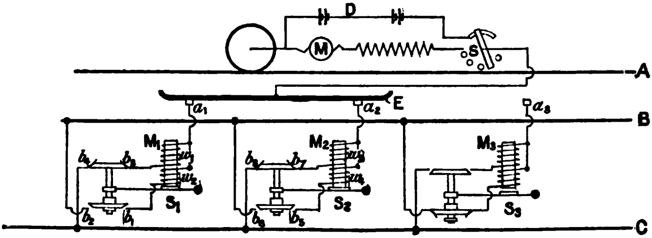


FIG. 44.

Author is aware, the first to patent a system in which surface-contacts or conductors are provided, with which a conductor attached to the car makes contact successively as it proceeds upon its journey. In Fig. 44, A, B are the rails upon which the motor-car or train is running. C is an insulated supply-feeder laid parallel with the track. The car is provided with a battery, D, a motor or motors, M, and a switch, S ; and underneath the car a sliding-conductor or shoe, E, is attached, which makes contact with the surface-conductors, a_1, a_2, etc., placed between the rails. The shoe E is long enough to make contact with two contiguous

surface-contacts, and the car is long enough to cover these contacts, which are, when it is over them, and then only, connected to the feeder C. The length of the car or train then limits the distance between the surface-contacts a_1, a_2, etc. There are preferably under the ground as many electro-magnetic switches, S_1, S_2, as there are surface-contacts. Each switch is provided with a magnet, M_1, M_2, etc., wound with two coils, w_1, w_2, w_3, w_4, etc., and the armature of each electro-magnet, when in its normal position, makes contact with two studs—b_1, b_2 in switch No. 1, b_5, b_6 in switch No. 2, and so on; S_3 shows the normal position of armature. But when the magnet is excited the armature is lifted, and contacts b_3, b_4, switch one, are made, and b_1, b_2 broken; but, since the lower contact-bridge piece is free to move on the shaft, there is a time during the operation when all four contacts are made. Suppose a car be in the position shown in the figure, and that the shoe E is in contact with contacts a_1, a_2; now make switch S. This allows the battery D to send an electric current round the coils w_2, w_4, which are of fine wire, in parallel, and so to the return conductor B. The armatures are lifted, and sever contact with b_1, b_2, b_5, b_6, respectively, making contact with b_3, b_4, b_7, b_8, thereby placing the shoe E in contact with the feeder; that is, the motor M can take current from the supply system through the thick coils w_1, w_3. When, finally, the shoe E breaks contact with a_1, and the motor-car moves from left to right, the armature of S_1 drops and closes the fine wire coil w_2 ready for the next car which enters the section.

It is stated that, in this system, by having supply simultaneously between two magnet coils in parallel, they may, owing to their different resistance—and each circuit has three contacts—so subdivide the current as to cause it to almost wholly traverse one magnet winding and not the other, thereby rendering the latter inactive.

Wheless.—The patent rights of this system are owned by

the Westinghouse Company, who have thoroughly tested it. It has been successfully at work in Washington for over a year on a branch line nearly a mile long, where a five-minutes' service was maintained, or twelve return trips per hour for twelve hours a day during 1895, one car running over 40,000 miles. The potential difference is that usually employed in tramway work, namely, 500 volts, and during the time it was at work no accident of any kind occurred. This is not the only example of this system having been tested. The Westinghouse Company have had it at work in their factory at Pittsburg, and it has proved of great convenience, since the shunting work in the shops is carried out without the smoke associated with the ordinary steam

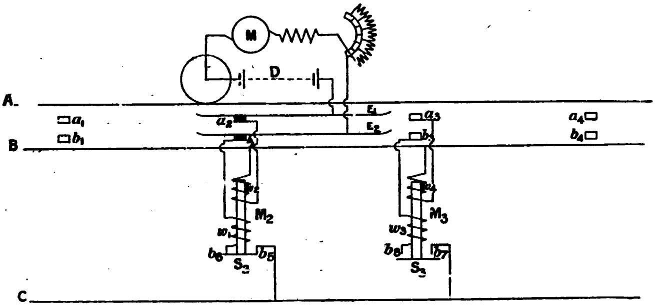


FIG. 45.

locomotive. Fig. 45 gives a diagrammatic sketch of the system. As in the Hopkinson system, A, B are the rails, C the insulated feeder, b_1, b_2, b_3 a row of surface-contacts which transmit energy from the supply-circuit to the motors when the switches, S_1, S_2, S_3, etc., are operated. The two rows of conductors are arranged side by side between the rails, as shown, and the car is provided with two sliding conductors, E_1, E_2, making contact respectively with the two rows of surface-contacts. The electro-magnets, M_1, M_2, etc., as in the Hopkinson system, are wound with two coils each;

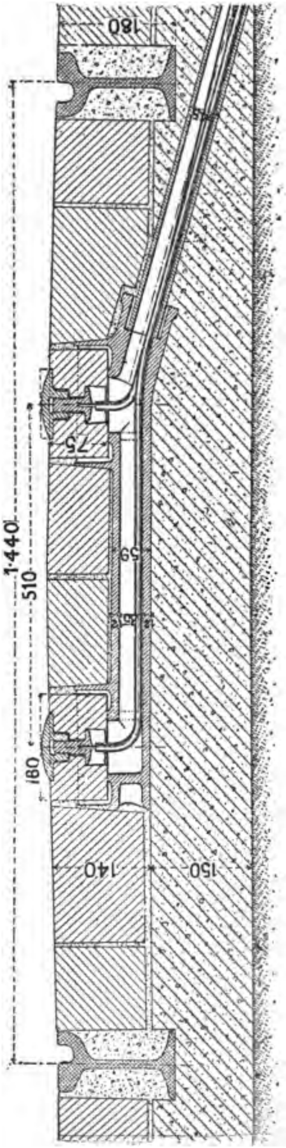


Fig. 46.

for instance, in switch S_2, w_1 is a thick wire coil, and w_2 a fine wire coil; the thick wire coil is connected to the surface-contact b_2, and the contact b_6 of the switch S_2, contact b_5 being connected to the feeder C. The fine wire coil w_2 is connected to the surface-contact a_2 and the return conductor B. Suppose a car to be placed as shown. The battery D can be made to send a current through E_1 to a_2, thence through coil w_2 to the return. This current operates switch S_2, and the conductor E_2 is connected to the feeder C through contacts b_5, b_6, and the coil w_1 in switch S_2. Energy can now be delivered to the motors to operate the motor M on the car. Fig. 46 gives a cross-section of the roadway showing the rails and a pair of surface-contacts or buttons in position. These buttons are about 10 or 12 centimetres in diameter, and stand about one centimetre above the ground level. The casting supports them firmly, and also provides means for leading in the conductors from the electro-magnetic switch. This latter has been very

carefully thought out with a view to accessibility, and replacing any part quickly. Fig. 47 gives sectional side and front elevations of the switch and electro-magnet, together

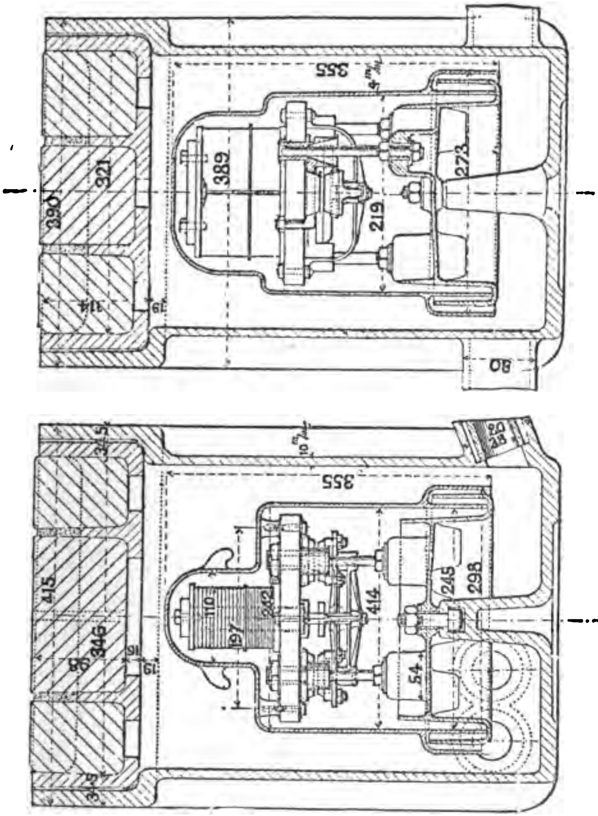


FIG. 47.

with the cast-iron box which contains these. The box is placed at the side of the rails and flush with the ground level. It also shows the electro-magnet supported by

means of a bell-shaped cast-iron box with the switch inside. The cables are brought in through water-tight joints in the

FIG. 48.

outer box, and led up through a circular casting to vertical pillars fixed to the same. When the bell-shaped top of the electro-magnet is placed in position, connection is automatically made with this vertical contact-rod ; and the bottom of the cover fits into a V-shaped circular groove, in which oil or other substance can be placed to render it air and water tight. The contacts b_5, b_6, in Fig. 45, are made of carbon, as shown in Fig. 47, and fixed to the core of the fine and thick wire solenoids. There is nothing, therefore, to prevent this core from dropping immediately the current in the solenoid is interrupted. Fig. 48 gives a view of the permanent way as installed at Washington. One sees nothing different from an ordinary horse tramway except these surface-buttons, which are automatically rendered dead when the car is not over them. The sliding conductors under the car are supported by springs from insulators on a cross-bar, and are slightly curved upwards at each end, so as to make sure of passing over the surface-contact.

Johnson-Lundell.—This system has been in operation at New York, and has demonstrated that surface-contact railways can be made a practical success. Like that of Wheless, this system has two rows of contacts on the surface, a_1, a_2, etc., b_1, b_2, etc., but these are not abreast as in the Wheless system ; they are as shown in Fig 49. A distinctive feature of this system is that there is no coil of wire on the electro-magnet between the feeder C and the contact series a_1, a_2, etc. This, of course, renders the system very secure against leakage. Another feature of this invention is that two electro-magnetic switches are operating at the same time and by the same current, as against one in the Hopkinson or Wheless. This will be best understood from the description. The car is provided with a battery, D, a switch, S, and a motor or motors, M. It has fixed to it, as in the Wheless system, two sliding-conductors, E_1, E_2, which are also long enough to project over two contiguous contacts in each series ; M_1, M_2, etc., are, as before, electro-magnets ;

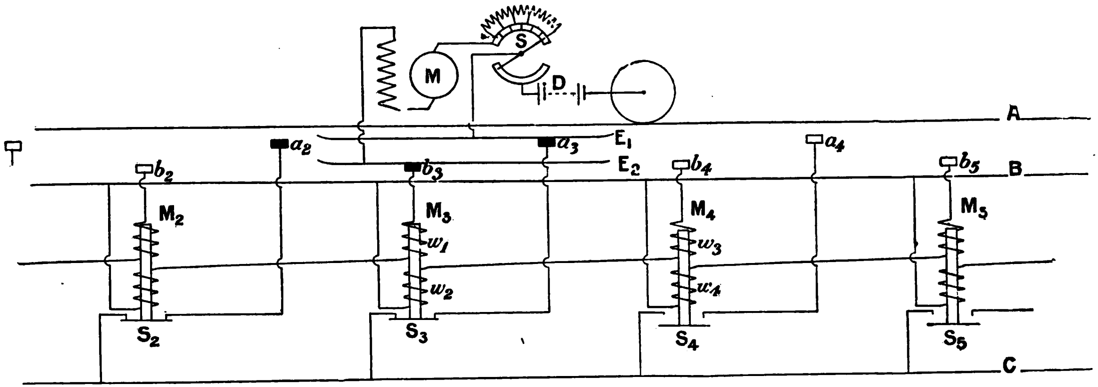


FIG. 49.

S_1, S_2, etc., are switches; and each electro-magnet is wound with two coils, connected in the following manner: Surface-contact b_4 is connected by a conductor to coil w_3 on magnet M_4, and is continued to coil w_2 on magnet M_3, and thence to the return conductor B. Similarly, b_3 is connected to the other coil w_1 on M_3, and continued through a coil on M_2 to the return B. The surface-contacts, a_1, a_2, etc., are connected to one contact of each of the switches, S_1, S_2, etc., the other contact being connected to the feeder C. Suppose all the switches, S_1, S_2, be down, and the switch S on the car be made. The battery D causes a current to flow through the motor or motors M to E_2, from thence through b_3, round the upper coil w_1 on magnet M_3 to the lower coil on magnet M_2, and thence to the return B. This makes switches S_2, S_3; that is, a_2, a_3 become charged, since they are connected to the feeder C through the switches S_2, S_3. The distance between a_2, a_4 must be covered by the car. The motor can now receive energy from the supply circuit through a_3, such supply-current now passing through the magnet windings on the magnets M_2, M_3, which we saw just now were traversed by the battery current. The advantage of this method of connection is that all the coils on the magnets are connected to the return B, and therefore they are kept at earth potential. By another arrangement of Johnson and Lundell, the contacts b_1, b_2, b_3, etc., are placed outside the rails, and therefore any surface leakage must get over or under the rails, if it proceeds from a_1, a_2, a_3, etc., before traversing the magnet windings, thereby making the system dangerous. In this latter case the surface-contacts b_1, b_2, b_3, etc., are in the form of longitudinal rails, thereby making the conductor E_2 much shorter; but it must be long enough to project over the space between the longitudinal rails.

The Lundell magnet is shown in Fig. 50. AA are blocks of carbon clamped to insulated supports, BB, and the object of the switch is to bridge across between AA when a current

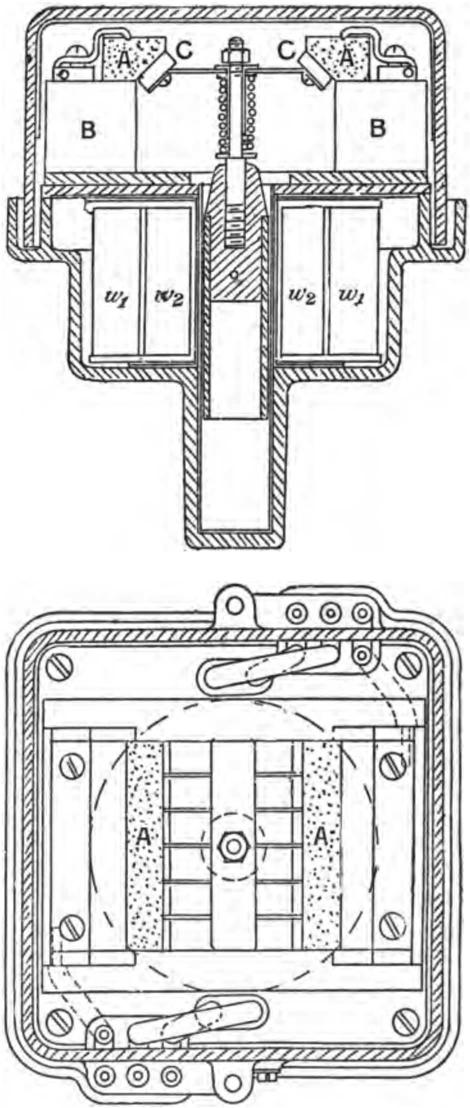


Fig. 50.

passes through the magnet windings. These windings, w_1, w_2, are shown in section, and surround a vertical bolt of soft iron, free to move vertically within them. An extension of the iron core carries six metal cross-arms, provided with contact-conductors, CC, of such shape that when the solenoid is energized by an electric current, the conductors make good contact with the carbon pieces AA. The whole is rendered waterproof by means of a cast cover which rests in a groove on the base as in the Wheless construction. We see that the Wheless and Lundell magnets consist of a solenoid and iron core, which is different to the form of electro-magnet generally met with. It is well known that if a potential difference be suddenly applied to the ends of the coil of an electro-magnet, the magnet does not immediately operate, owing to the reaction of the magnet upon the circuit. Quickness of action is of importance in tramway working, especially if the speed is great. A speed of ten miles an hour corresponds to about five yards per second, and this might be the length of the skate or collector under the car, that is, at this speed contact might be made with a button for one second. We see, therefore, how important it is to have an electro-magnet which acts at once, so that the contact between feeder and button may be as long as possible.

Taking the different systems in order, and as shown in Figs. 44, 45, 49, we see that in Hopkinson's, when the shoe touches two buttons, the switch holds solely by the current passing through the thick coil, and therefore unequal division of current in the two parallel coils may result in the failure of one magnet to act properly. The same remark might apply to Wheless', so far as the thick coil is concerned; but the current through the thin wire coil is not automatically interrupted when the armature lifts, and action is therefore certain. In the Johnson-Lundell no thin wire coil is employed; but, since there are always two coils in series, the coils being on contiguous magnets, it

follows that, for a given current in the motor, if the turns be the same on each coil of each magnet, the one magnet must have the same net ampere-turns in spite of unequal division of current, and action is certain.

With regard to leakage, taking the diagrams as they stand, we see that in Wheless the earthed coil is the coil excited by the battery, and therefore the more nearly the potential difference of this battery is equal to the maximum potential difference of the system, the more secure is the system against operation of the magnet by leakage. The castings which support the buttons, if put directly to the rail return, would help considerably to shield such buttons from leakage. In the Johnson-Lundell, all the coils are to earth, but they have low resistance; it is therefore necessary to shield the buttons connected to such coils as much as possible from leakage, and for this reason in practice the rail is placed in between the two series of buttons shown in the diagram.

The Author inclines to the opinion that, since power is lost by departing from the nearly closed magnetic circuit, the best way would be to operate such magnets at the maximum potential difference of the system, interposing in the circuit of the magnet a considerable resistance as non-inductive as may be. In this way, during the initial stages, when the current is small, nearly the whole potential difference would be applied to the magnet, thereby making it act quicker, and leakage would not operate such magnet since the maximum potential directly applied is necessary to do this.

Esmond's British Patent, No. 22519 of 1895.—This patent describes a system in some respects resembling those just described. Esmond arranges his surface-conductors in sets of three, and excites the magnets of advanced sections, thereby attaining, to some extent, the same results as with the two magnets in the Johnson-Lundell system.

Wynne.—This is an allied system to those just mentioned, and has been tried on an experimental line at

Wolverhampton. Mr. Thomas Parker has given a favourable report on this system.

Claret-Wiulleumier.—This system has been at work in Paris for some considerable time, on a line $4\frac{2}{3}$ miles long, of which $2\frac{1}{2}$ miles are in the city. The maximum gradient is 1 in 21·7, and there are numerous curves, some having a radius of 97 feet. The generating station contains three 200-H.P. horizontal type condensing engines, each driving by belt a 140-kilowatt four-pole over-compounded generator, giving 500 volts potential difference. The surface conductors in this system consist of metallic buttons embedded in bitumen eight feet apart, connected in pairs by an underground cable having a cross-sectional area of 0·012 square

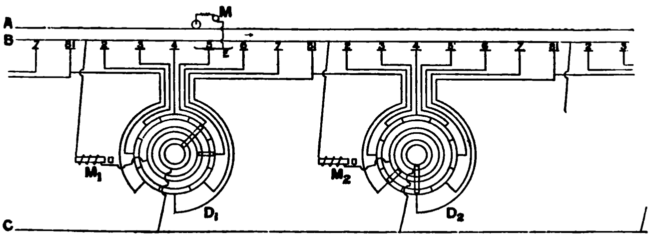


FIG. 51.

inch to the supply-feeder by means of automatic switches called "distributors." A conductor, ten feet long, fixed underneath the car, makes contact with these surface-conductors, and consists of an iron band pressed down upon the contacts by springs. There are two supply-feeders, one $3\frac{3}{4}$ miles long and 0·46 square inch section, the other $1\frac{1}{2}$ miles long and 0·35 square inch section. Fig. 51 gives a diagram of connections, from which it will be seen that the surface-contacts are divided into groups. In Paris there are 18 per group, each group being connected to an underground distributor. In the sketch only eight contacts are shown with each distributor, D_1, D_2. This number, of

course, depends upon the distance between the cars and the distance between two consecutive contacts on the line. Initially, the distributor is as shown in D_2. There are two brushes bearing on contiguous contacts, each brush being connected to metallic rings, on which a single fixed brush bears. The distributor is driven by means of a weight, or motor, in such a manner that it carries round the two rings with their brushes so as to make contact with the blocks 1, 2, 3, 4, etc., successively. Suppose a motor-car is in the position shown, that is, the conductor E is making contact with No. 5 button. The current can pass from the feeder C to the inner ring of the distributor, thence to contacts 5, 5, on distributor and surface, through the motor M, to the return A. If the car moves in the direction of the arrow, it will bring the collector E into contact with No. 6. The current can now pass from this contact to No. 6 in the distributor, through the coil on the electro-magnet M_1, to the return B. This magnet, when operated, releases the mechanism which turns the distributor to the next position, thereby placing the brushes on 6 and 7 respectively. The motor M now takes its current from contact 6, through the distributor, instead of contact 5. Surface-contact 8 is connected by means of a cable to No. 1 on the next distributor; and so the car, when arriving there, begins to operate distributor D_2, and so on, leaving distributor D_1 at its initial position, ready for the next car. If the distributor should fail to act and the car goes forward, it must be turned round until it is in the proper position for the then position of the car. This is clearly a defect in the system, as here described, but it may now be remedied. Another defect in this system, as regards tramways, is that two cars cannot be in the same section at the same time, as the distributor would not have worked round, and consequently would not supply current to a second car. This, however, becomes a decided advantage in the case of railways, constituting a sort of block system. Means are provided for

reversing the distributor so that the cars can traverse in either direction. The cars are 28 feet long, and take 56 passengers, with a compartment for luggage. There are on each car, two single reduction motors. The number of cars running is 15, and 5 are under construction. The service is a five-minutes' one. Street lighting is carried out by means of 10 ampere arc lamps, 9 in series, and 14 such circuits.

CHAPTER VII.

STORAGE-CELLS.

General Remarks.—Before entering upon the actual application of storage-cells to traction work, it will be well to look into one or two matters in connection with storage-cells generally. Let a fully charged storage-cell be discharged, say, by placing a rheostat and current meter between its electrodes, and let the current be kept constant by variation of the resistance. Place a voltmeter across the terminals of the cell, and before starting the discharge, let the volts be registered; as the discharge proceeds let them be observed and plotted in terms of time. The general result is that the potential difference drops immediately on making circuit, the extent of the drop depending upon the internal resistance of the cell and the magnitude of the current; a slight recuperation occurs, and then the potential is maintained almost constant for a considerable time; finally, the potential begins to fall rapidly, and if the test be continued it drops to zero. The point at which the potential difference begins to rapidly diminish depends upon the rate at which the cell is being discharged, and the density of the acid employed. It is usual not to discharge cells beyond the point at which rapid drop of potential sets in. The usual figure to take for this is 1·7 to 1·85 volts, according to the rate of discharge. The area bounded by the current curve between the ordinates at time zero, when the discharge starts, and any other time, and the base-line gives the total quantity discharged in that time,

say in ampere-hours. Let a curve be drawn giving the products of volts and amperes at any moment. Then the area bounded by this curve and the ordinates at time zero, and any other time, and the base-line gives the actual work done in that time on the circuit by the cell in, say, watt-hours. If a series of charges and discharges be carried out, the minimum volts on discharge being, say, 1·8 to 1·7 according to current, the ratio of watt-hours and ampere-hours on discharge and charge give respectively the work and quantity efficiency of the cell; the criterion with regard to full charge being the abundant liberation of gas at the plates. But due notice must be taken of the rate of charge. If the rate be great, gas will be liberated at the plate before the cell is properly charged, and the test should be continued for a longer time in order to properly charge the plates. A fair figure for lead batteries is about 90 per cent. for quantity and 80 per cent. for work efficiencies respectively, but the latter may drop below 70 per cent. (see p. 140) for high rates of discharge. For instance, it is stated in connection with the Tudor stationary cell, that the work efficiency is 80 per cent. for the 3 to 10 hour rates, and 75 per cent. for the 1 to 3 hour rates. Let a series of discharges be made each with constant current, but let the currents be gradually increased with the successive discharges, and let us take as a criterion either that the discharge be stopped when the volts are 1·75, say, or that it be stopped when the net drop in volts between their initial and final values with the current passing is, say, 0·2. It is found that the total discharge in ampere-hours becomes smaller as the current is increased; or you can put it this way—if the rate at which you discharge a cell be halved, the test is continued for more than double the time before the limiting conditions are reached, and consequently the ampere-hours are greater. This is well shown by the curves in Fig. 52, which give the total quantity in ampere-hours, the rate of discharge in amperes in terms of the time

during which the test is continued for one Electrical Power Storage Company's K type plate, measuring about $9\frac{3}{4}$ by 9 inches and the same Company's Faure-King type central-station cell-plate, the data being taken from the 1897 list. Take the K type. We see that if we spread

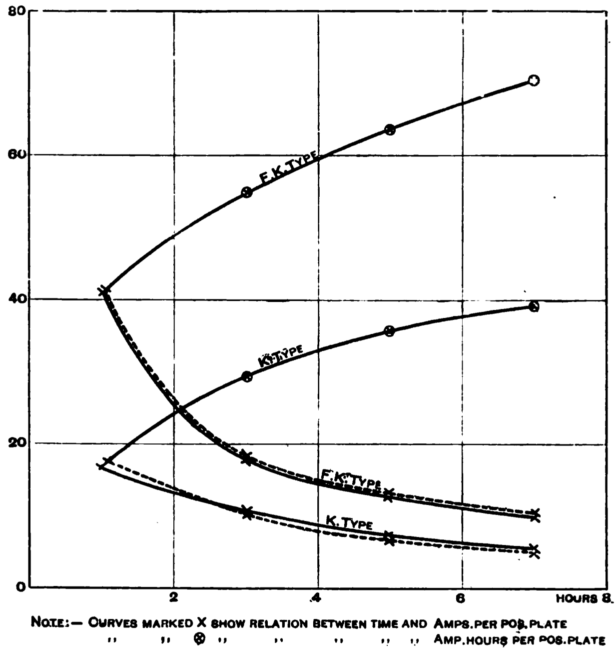


FIG. 52.

the discharge over seven hours, the amperes being 5·6, the quantity in ampere-hours is 39·3, whereas, for one hour, if the amperes are 17·5, the quantity is only 17·5 ampere-hours. The Faure-King type shows the same character of result, and the intermediate points at three and

five hours have been calculated by the Author on the same basis as in the K type.

The data given in the Electrical Power Storage Company's 1897 Price List show that for a given time of discharge, before the limiting conditions are reached, the amperes at which the cell can be discharged are proportional both to list price and total weight of the complete cell. The data given in connection with the Tudor cell give the same character of result.

We see, therefore, that when specifying the capacity of storage-cells, care must be taken to give the limits with regard to time of total discharge, final volts with current passing, and the rate in amperes.

Economy.—The question may be asked for a given cell—At which rate is it best to charge or discharge? In answering this the actual requirements must be carefully studied. Economy of working must be viewed from more standpoints than actual efficiency; that is to say, high efficiency does not necessarily mean best economy. For instance, it might be more economical to work a small battery at high rates of charge and discharge with diminished life, if by so doing a great saving can be effected by doing away with the removal of cells from the car. If positive plates could be made very cheaply, the actual life of the cell would become of less importance, and in any case the maintenance of storage-cells is in this connection a most important item. Central station-cells are maintained at from $3\frac{1}{2}$ to 10 per cent. of the first cost, according to the conditions of working;* but in traction work, with the cells on the car, the maintenance would probably be higher if high rates of charge and discharge are employed, and it is usual to quote a rate for maintenance per car mile. For instance, the Birmingham Tramways paid 1*d.* per car mile for maintenance (see *Electrician*, August 26, 1892). At Hanover the cost of maintenance per car mile is 0·15*d.* (see p. 146).

* See p. 197 for maintenance of storage-cells at Leeds.

With regard to the life of a cell for given working conditions, only experience over a considerable time will enable one to obtain definite information. The life of ordinary station-cells is well known; it depends upon the type of cell, but four years is a fair average figure, if the cells receive proper care and attention.

Density of Acid.—The acid, too, is a very important element in a lead storage-cell. Apart from purity, the density has much to do with the life and working of the cell. Table VII. is taken from Everett's "Tables of Physical Constants," p. 180, edition 1891, and refers to the specific resistance of dilute sulphuric acid.

TABLE VII.

Density.	Specific resistance.			
	At 0° C.	At 8° C.	At 16° C.	At 24° C.
1·10	$1{\cdot}37 \times 10^{10}$	$1{\cdot}04 \times 10^{10}$	$0{\cdot}845 \times 10^{10}$	$0{\cdot}737 \times 10^{10}$
1·20	1·33 ,,	0·926 ,,	0·666 ,,	0·486 ,,
1·25	1·31 ,,	0·896 ,,	0·624 ,,	0·431 ,,
1·30	1·36 ,,	0·94 ,,	0·662 ,,	0·472 ,,
1·40	1·69 ,,	1·30 ,,	1·05 ,,	0·896 ,,
1·50	2·74 ,,	2·13 ,,	1·72 ,,	1·52 ,,
1·60	4·82 ,,	3·62 ,,	2·75 ,,	2·21 ,,
1·70	9·41 ,,	6·25 ,,	4·23 ,,	3·07 ,,

We see that the specific resistance is a minimum for any temperature quoted at a density of 1·25; but the variation of resistance on either side of this density, within small limits, is not great. 1·25 would seem, therefore, from conductivity to be the best; but a density not so high as this is generally adopted in actual practice. The Electrical Power Storage Company state that the specific gravity, when the cell is fully charged, should be from 1·2 to 1·21, and the discharge should never be continued after the specific gravity has fallen to 1·170. These densities are

very near those of maximum conductivity given in the above table. The Chloride Electrical Storage Syndicate state 1·215 as the specific gravity for the fully charged cell. A high density has the effect of keeping up the volts on discharge, but it probably shortens the life of the plates.

The specific gravity of the acid and the colour of the plates are fair criterions as to the state of the cell; but the potential difference with current passing is the best guide when discharging.

Methods of Working Cells.—We find storage-cells used at the present time in traction work in the following ways:—

(1) In the central station or power-house proper.

(2) On the car itself; (*a*) where the whole power taken to propel the car comes from the cells; (*b*) where the cells are used in conjunction with an overhead or underground conductor, or with a surface-contact system.

(3) In feeder substations.

(4) On the car itself for lighting purposes only.

The Use of Storage-Cells in the Power-house.—As regards this division, we have seen that the fluctuations of power delivered to the line by the power-house is considerable, and to meet a sudden call for heavy discharge the storage-cell is no doubt well adapted, and especially is this the case on small systems. There are several instances of batteries being used in parallel with the generating dynamos, just as in an ordinary electric lighting station. In the combined lighting and traction station at Rome, for instance, a battery of 300 Tudor storage-cells of about 1000 ampere-hours capacity is placed in parallel with the station machines, and the regulating cells are varied in steps of three at a time for the purpose of keeping the potential constant. At Hamburg, which is another notable instance of combined lighting and traction station, a large battery of storage-cells is employed in the power-house; and the sub-stations are provided with motor-generators

and storage-cells. Zurich is another instance of the employment of storage-cells in central stations for traction purposes.

The Use of Storage-Cells on the Car.—(*a*) A self-contained car equipped with storage-cells is no doubt, in some respects, the ideal motor-car, the success of which at the present time depends upon the storage-cell and its management. The storage-cell is used on cars as the only propelling power, and to make it as successful financially as the overhead trolley, a low first cost and maintenance are the great things to be aimed at. On a tramcar, for instance, since the whole weight may be on the driving wheels, it follows that lightness is a clear gain, not only on account of the actual weight to be carried, but also on account of the permanent way. A battery of storage-cells on an ordinary tramcar, which would weigh about 10 tons, with passengers but without storage-cells, may weigh from $1\frac{1}{2}$ to $2\frac{1}{2}$ tons. Two enclosed geared motors weigh about $1\frac{1}{3}$ tons for such a car, so that the battery is an important extra so far as the weight is concerned, and of course this is an objection. This aspect would not be so bad if the battery were used on a locomotive drawing a train of carriages. We find the storage-cells placed under the seats of cars in many places; but no doubt the best arrangement is to make the undertruck to carry the cells as well as the motors. The Peckham storage-cell truck is illustrated in Fig. 53, from which it will be seen that the cells can be placed in between the car axles and the motors overhang, having their usual place occupied by the cells; this arrangement has the advantage that great strength can be secured for their support whilst they are removed from the woodwork of the car, and are not so liable to be troublesome to passengers. The cells can be very conveniently lowered into a pit under the car, and this method is adopted at New York. The storage-cell used on cars is, as a rule, enclosed in teak lead-lined boxes, although ebonite is

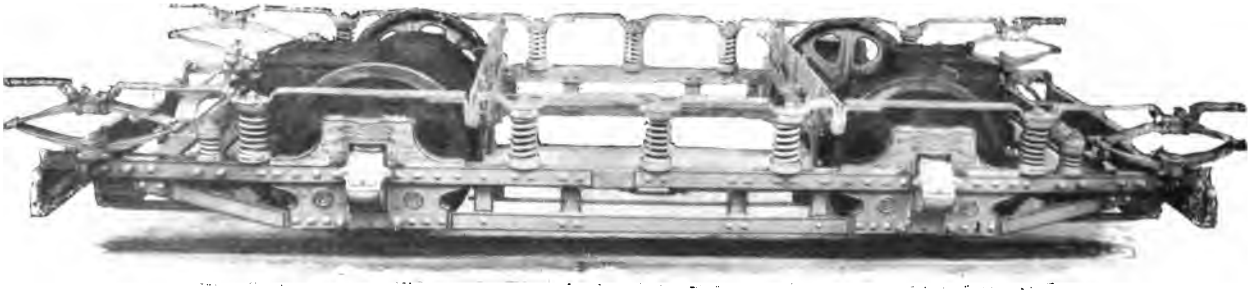


Fig. 53.

sometimes used. The number of elements and their capacity vary with the requirements of the car and the method of working. We are at present considering the storage-cell when worked at rates commonly used with cells, and therefore the battery must be removed from the car, properly charged over a considerable time, and its place filled by another one. The handling of storage-cells in this system is an important item, to set against which one must consider the longer life of the cell.

Birmingham.—During the last seven years storage-cells have been persevered with at Birmingham. The line is about three miles in length, and equipped with twelve motor-cars. It is stated that for the year 1893 the number of car miles run was over 140,000, and the total cost per car mile was 11*d.* This figure is of course very high, the most important item included therein being 5*d.* for repairs and maintenance.

The Author is indebted to the Chloride Electrical Storage Syndicate for the following particulars with regard to the working of their cells on this line. For upwards of three years to June, 1897, this company have been running the cars at Birmingham, during which time the aggregate mileage run has been 383,000 miles. The battery in each car consists of 72 cells, some with 11 and some with 13 plates of the chloride TR type, the positive of which measures $10 \times 7 \times \frac{5}{16}$ inches, and weighs $6\frac{1}{2}$ lbs. when dry. The negative plate measures $10 \times 7 \times \frac{3}{16}$ inches, and weighs dry 3 lbs. 3 ozs. The cells are placed under the seats of the carriages; the weight of the battery in each car is 50 cwts., and the cars themselves weigh about 10 tons. The average mileage per car per diem during the three years has been 65.

New York.—The cars on the Maddison Avenue, New York, line are equipped with storage-cells of the Philadelphia Electric Storage Battery Co. The trucks are constructed as above described, and each is supplied with two General

Electric motors. There are 60 cells per truck, arranged in two sets of 30 each, and a very convenient method of lowering the complete battery from the truck into a pit underneath is adopted, connection being automatically made with the poles of the cells when in position. The proper handling of cells is a point the importance of which cannot be over-estimated, and this method seems to give special facilities. The superficial area occupied by this battery is about 24 square feet, and the controller is so arranged that initially the two sets of 30 cells each are placed in parallel, with the motors in series; whereas, finally, the motors are in parallel, with their windings shunted for high speeds, the 60 cells being in series, and the potential difference about 120 volts. The different stages are shown in Fig. 54, and are carried out by means of a controller similar to that described in Chapter II.

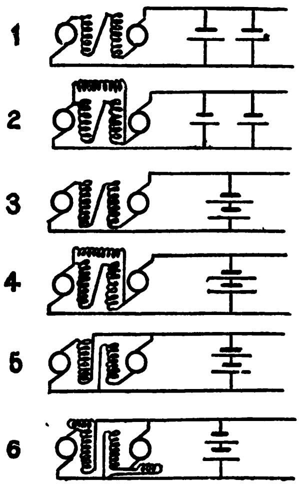


FIG. 54.

The capacity of these cells is 400 ampere-hours.

Paris.—The Paris tramways furnish a very good example of the employment of storage-cells in traction work. Three lengths of line, as under, are equipped with two distinct types of cars—

	Miles.
Madeliene—Saint Denis	5·7
Opera—Saint Denis	5·7
Neuilly—Saint Denis	2·73
Total	14·13

The first type contains 108 Laurent-Cely type storage-cells, having a capacity of 175 ampere-hours at a mean current

of about 35 amperes, placed under the seats. There are nine cells in a box, and six such boxes on each side of the car, which carries 52 passengers. The weights, etc., are stated by Maréchal* to be as follows :—

Car, 17,600 lbs.; battery and accessories, 6610 lbs. = 2·95 tons; passengers, 7720 lbs.; total, 14·3 tons.

A fully charged battery takes the car 31 miles. The motors have double reduction gear, and are worked on the series-parallel control system. There are three steam-engines in the power-house, each driving by a belt a shunt machine giving about 260 volts. The working expenses per car mile in 1893 are stated to be a little over 8*d.*, of which $2\frac{1}{2}$*d.* goes towards maintenance and handling of cells.

The second class of car has the cells placed on the under-truck between the axles, as is the case at Maddison Avenue (see p. 135), and there are 56 cells instead of 108. The advantages gained by this arrangement are reduced weight and labour in charging operations. The weights are as follows :—

Car, 14,300 lbs.; battery, 3750 lbs. = 1·76 tons; passengers, 7720 lbs.; total, 11·5 tons.

A feature of these cars is the arrangement whereby the energy due to gradients (see p. 10) on descending is returned to the cells by converting the motors into generators. Allowing for efficiency on two parts of the track, namely, Rue de Rome and Avenue de Saint Ouen, 27·3 and 21·8 per cent., respectively, of the total energy is given back to the cells by the motors on the cars.

The Paris tramways also give an illustration of rapid rates of charge and discharge, whereby the cells are never taken from the truck, but at the end of the journey the charge is effected as the car stands, in, say, a quarter of an hour. There are four lengths of line having a total length of about 15 miles as follows :—

* See *Les Tramways Electriques.*

	Miles.
Madeliene—Courbevoie	4·18
Madeliene—Bineua Courbevoie	4·10
Madeliene—Levallois	2·93
Neuilly—Avenue du Roule	3·55

The cells are charged at a centre common to the four lines by means of feeders, each transmitting energy from a distant station. The cells are of the Tudor type, and each car contains 200 5-plate cells, the plates having the dimensions of 21 cms. high and 21 cms. broad. The weight of a cell is 33 lbs., and the entire battery 3·45 tons. The minimum guaranteed capacity is 32·5 ampere-hours for a going and return journey at a maximum speed of 10 miles per hour out of Paris, and 7·5 miles per hour in Paris. If we assume the length of journey to be eight miles, this gives about 1½ Board of Trade units per mile (see p. 50). The cells are charged in series at 540 volts, the current being 120 amperes, which corresponds to about 8 amperes per kilogram of plate. There are 35 cars on the four lines, each of which with passengers weighs about 14 tons. This novel way of dealing with the problem will be watched with interest. It remains to be shown whether this method, which does away with the cost of handling the cells, is on the whole cheaper. We see that for the weight the capacity is small, and this is what one would expect with such high rates of discharge.

Under this system of rapid charge there is no reason why provision should not be made at certain points along the route for automatically making contact with a charging feeder, so that the cells could be charged as the car stands. For instance, an ordinary pole could support a contact making-piece, which would be automatically connected as the car runs underneath.

The copper-zinc storage-cell is deserving of attention, as being a rival to the lead storage-cell for traction work. In the Desmazures cell the positives are composed of fine copper powder compressed upon copper gauze or net, under

a pressure of from 800 to 1200 kgm. per square centimetre, and have a total thickness of about seven mms. over the paper cells which surround them. The negatives are made of steel-wire netting, about eight to nine mms. thick; the plates being placed in an alkaline-zincate * solution. Although the potential difference of these cells is low, about 0·8 volt, their weight efficiency is stated to be high. In America the Waddell-Entz cell has attracted attention, and differs only from the Desmazures in constructive details. The copper-zinc cell is being used at Vienna, and appears to give satisfactory results; but the Author has no exact figures with regard to maintenance and general expenses.

The Author has recently carried out, in conjunction with Mr. H. H. Hodd, a series of experiments upon two totally different types of traction-cells, and he wishes to thank this gentleman for his assistance. The experiments were made in the Siemens Laboratory, King's College, London.

The first type is a Faure-King five-plate traction cell, supplied by the Electrical Power Storage Company. It is a pasted cell, the active material of which is secured to the surface of an almost non-oxidizable conductor; the plate is then inserted in a perforated envelope, composed of a material capable of resisting destructive action on the part of the oxides, the gases, and the electrolyte, such envelope being secured to the plate by means of a series of bolts and washers of this material.

The two positive plates measure each $7\frac{1}{4} \times 8$ inches, and have a thickness of $\frac{1}{4}$ inch, not including the envelope. They weigh, with lug, when just taken out of the acid, 7 lbs. 7 oz. The total weight of the cell in ebonite box and acid is 21 lbs. 2 ozs. The specific gravity of the acid in the fully charged cell is 1·275.

The second type is that of the Chloride Electrical Storage Syndicate, and known as their P.R. type 11-plate cell. Two of these cells were supplied to the Author for the

* A solution of zinc hydroxide in excess of alkali.

purpose of these tests, by Mr. Grindle, the manager of the Syndicate.

Each cell has five positive plates, each measuring $5\frac{1}{2} \times 7$ inches, and $\frac{1}{4}$ inch thick. The five plates with lug, weigh, when just taken out of the acid, 16·5 lbs. The total weight of the cell in ebonite box and acid is 36 lbs. The specific gravity of the acid of the fully charged cell is 1·200.

The positive plates consist of spirals of lead strip inserted in a skeleton of harder material, and therefore represent, so far as absence of paste is concerned, the original Planté cell. The negatives are the ordinary chloride type, with hexagonal pastilles of spongy lead, round which is cast the sustaining grid.

It must be clearly understood that these tests have been made upon new cells, and therefore no conclusions can be drawn as to the life of such plates; and, further than this, tests upon three isolated cells like these may not represent the average results obtained from many.

The potential differences were taken all through by balancing against a Clark's standard cell by Poggendorff's method. The currents were measured by a Siemens electro-dynamometer, which could be checked at any time by measuring the potential difference between the ends of a known standard resistance in the circuit by means of Clark's cell and Poggendorff's method. The ampere-hours and watt-hours on discharge are very reliable; but this is not the case on charge for the high rates, owing to the uncertainty when a cell is properly charged. We have already stated that gas freely liberated at each plate is a good criterion that the cell is charged; but at high rates gas is certainly liberated before the cell may be said to be fully charged, owing, no doubt, to the time required for proper penetration. There is no doubt but that, in the working of cells at high rates, a long steady charge (say at night) at a low current density, would prolong the life of the cell.

In the tests here described, the criterion as to when the cell is sufficiently discharged has been to allow a 0·2 volt drop on the potential difference of the cell when this is steady, two or three minutes after switching on. The results are given in Tables VIII. and IX. (pp. 141, 142, and 143).

In the case of the Faure-King cell, the one-hour rate final volts are 1·7 as against 1·85 at the nine-hour rate. The points marked × in Fig. 55, give the ampere-hours and watt-hours in terms of the total time of discharge in

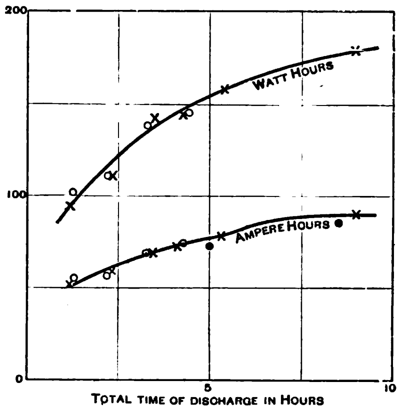


FIG. 55.

hours before the limiting conditions are reached. The quantity efficiency remains high all through, but the work efficiency from the figures, drops from about 73 per cent. at the five-hour rate to about 62 at the one-hour rate. In the figure, the points marked • are taken from the E.P.S. 1897 List; the agreement is good. It will be noticed that the charge, after any discharge is accomplished at a higher current density per plate than was the case in the discharge.

The points ⊙ in Fig. 55 give, for the Chloride cell, the

TABLE VIII.

Test of a Faure-King 5-Plate Traction-Type Storage Cell.

Discharge.

No. of test.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
Volts when current is zero; *i.e.* open circuit just before starting test	—	—	—	—	2·183	2·15	2·19	2·19	—	—	—	—	2·14	—	—	—
Volts when they are fairly steady almost immediately after switching on current	2·05	2·05	2·04	2·02	2·008	2·003	2·013	2·01	1·987	1·976	1·99	1·965	1·96	1·942	1·96	1·899
Final volts at end of test; current passing	1·84	1·85	1·85	1·85	1·81	1·8	1·802	1·8	1·8	1·775	1·775	1·76	1·76	1·591	1·7	1·7
Amperes constant at ...	10·0	10·0	15·0	14·9	18·1	18·1	18·1	18·1	18·0	21·4	21·4	27·2	26·9	27·7	41·3	41·5
Total time of discharge in hours and minutes	h. 9	h. 9	h.m. 5.20	h.m. 5.15	h.m. 4.15	h.m. 4.10	h.m. 4.0	h.m. 4.4	h.m. 4.1	h.m. 3.27	h.m. 3.23	h.m. 2.22	h.m. 2.13	h.m. 2.3	h.m. 1.19	h.m. 1.13
Ampere-hours	90·0	90·0	80·0	78·2	76·9	75·4	72·4	73·5	72·3	73·8	72·4	64·3	59·6	56·7	54·4	50·5
Watt-hours	175	175	157	155	147	146	138	141	140	142	139	117	111	105	100	92
Work efficiency ..	—	—	68·8	76·1	75·6	65·9	63·6	65·8	71·0	68·9	74·3	72·7	71·4	67·1	57·1	68·1
Quantity efficiency ...	—	—	82·0	89·7	91·6	81·1	79·2	81·6	89·0	82·7	92·4	94·0	90·5	87·0	81·8	95·2

TABLE VIII.—*continued.*

Test of a Faure-King 5-Plate Traction-Type Storage Cell.

Charge.

No. of test.	6	8	10	12	14	16	18	20	22	24	26	28	30	32
Volts when current is zero; *i.e.* open circuit just before starting test	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Volts when they are fairly steady almost immediately after switching on current	2·135	2·15	2·18	2·18	2·183	2·2	2·209	2·165	2·187	2·2	2·217	2·23	2·306	2·32
Final volts at end of test; current passing	2·6	2·59	2·69	2·6	2·62	2·614	2·668	2·572	2·577	2·639	2·64	2·644	2·725	2·75
Amperes constant at	17·8	17·8	21·0	21·0	21·5	18·0	21·2	21·4	21·4	28·3	28·2	28·0	50·0	50·5
Total time of discharge in hours and minutes	h.m. 5.30	h.m. 4.54	h.m. 4.0	h.m. 4.25	h.m. 4.15	h.m. 5.0	h.m. 3.50	h.m. 4.10	h.m. 3.40	h.m. 2.25	h.m. 2.20	h.m. 2.20	h.m. 1.20	h.m. 1.3
Ampere-hours	97·9	87·2	84·0	93·0	91·4	90·0	81·2	89·2	78·3	68·4	65·8	65·3	66·6	53·0
Watt-hours	228	203	195	221	217	215	197	206	187	161	156	156	176	135
Work efficiency	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quantity efficiency	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE IX.

Test of a Chloride Electrical Storage Syndicate's "P.R." Type 11-Plate Cell.

	Discharge.								Charge.							
No. of test.	1	3	5	7	9	11	13	15	2	4	6	8	10	12	14	16
Volts when current is zero; *i.e.* open circuit just before starting ...	—	—	—	—	2·051	2·056	2·15	2·056	—	—	—	—	—	—	—	—
Volts when fairly steady almost immediately after switching on current	1·997	1·976	1·956	1·94	1·936	1·932	1·932	1·899	—	—	—	—	—	—	—	—
Final volts at end of test; current passing	1·8	1·749	1·775	1·667	1·74	1·771	1·7	1·7	2·473	2·5	2·49	2·523	2·55	2·569	2·641	2·665
Amperes constant at ...	18	21·4	21·4	27·1	26·9	27·6	41·3	41·5	21·2	21·3	21·4	28·3	28·1	28·0	50·0	50·5
Total time of discharge in hours and minutes	h.m. 4.12	h.m. 3.25	h.m. 3.12	h.m. 2.15	h.m. 2.8	h.m. 2.3	h.m. 1.26	h.m. 1.20	h.m. 4.30	h.m. 4.0	h.m. 3.15	h.m. 2.15	h.m. 2.20	h.m. 2.20	h.m. 1.20	h.m. 1.10
Ampere-hours	75·6	73·1	68·5	61·0	57·4	56·6	59·2	55·3	95·4	85·2	69·5	63·6	65·6	65·3	66·6	58·9
Watt-hours	144	145	130	114	110	106	112	99	214	195	155	143	149	150	156	137
Work efficiency	67·2	76·3	83·8	79·7	73·8	70·6	71·8	72·2	—	—	—	—	—	—	—	—
Quantity efficiency ...	79·2	85·8	93·5	96·0	87·5	87·0	88·9	93·9	—	—	—	—	—	—	—	—

ampere-hours and watt-hours in terms of total time of test before the limiting conditions are reached. These results, in each type of cell, can be expressed in terms of ampere-hours and watt-hours per pound of positive plate, or per square foot of superficial area.

It is interesting to note the relation between the weight of a battery of cells and the distance such a battery would propel a tramcar when discharged at a given rate. Take, as a basis, that one kilo-watt-hour is required to drive a tramcar one mile at the average rate of seven miles an hour. Take the case in which a cell discharges 110 watt-hours in 2·25 hours, the average rate of discharge is $\frac{110}{2{\cdot}25 \times 1000}$ kilo-watt-hours per hour. In 2·25 hours the whole battery must discharge 16 Board of Trade units, the car travelling 16 miles; therefore, if the weight per cell be 30 lbs., the weight in tons of the battery would be 1·95. The above is only approximate, since the rate of discharge at starting may be three times what it is when the car is running at its maximum speed, and the discharge in watt-hours does not vary as the total time. The number of such cells would be 145, and the volume they would occupy at 0·16 cubic foot per cell, would be about 23 cubic feet.

If reference be made to the Locomotives on Highways Act, 1896 (see Appendix, p. 240), it will be seen that a "light locomotive" means a vehicle propelled by mechanical power which is under three tons in weight unladen, that is, without storage cells, if these be used for propulsion. If the weight unladen is $1\frac{1}{2}$ ton, and does not exceed two tons, the locomotive shall not be driven at a greater speed than eight miles an hour; or, if the weight exceeds two tons, five miles an hour.

Take a cell weighing about 30 lbs., and capable of discharging 100 watt-hours in $1\frac{1}{4}$ hour, that is, at a rate of $\frac{100}{1{\cdot}25}$ watt-hours per hour. Assume that to drive a "light

locomotive," a battery of storage cells must discharge at the average rate of 3 H.P. Then the number of cells in the battery would be 28, and the weight 840 lbs., or 0·375 ton. These cells would occupy a floor space of about six square feet, if placed in one layer.

The Use of Storage-Cells on the Car.—(*b*) One of the most interesting applications of storage-cells to traction purposes is the combination of cells on the car with overhead trolley conductor, as used at Hanover, or with the slotted conduit as at Dresden. In crowded thoroughfares there is an objection to the overhead conductor, and of course one can combine the trolley-wire, which can be used outside the town, with a surface-contact system, slotted conduit system, or storage-cells. The change over from the trolley-wire to surface-contact is very convenient; not so the slotted conduit and trolley-wire, since the "plough," as it is termed, or the instrument used to collect the energy from the live underground conductor, has to be placed in and taken out when entering and leaving the sections; although with proper management this can be carried out in about a quarter of a minute. The storage-cell is also convenient, since it can be made of sufficient capacity to take the car between termini and trolley-wires and gets automatically charged from the trolley-wire, as in the case of Hanover.

Hanover.—The tramway system has a length of about 32 miles on which electric traction is used, and 17 on which horse traction is used. The standard gauge is employed, and the maximum gradient is 3·5 per cent., which is favourable for storage-cell traction. There are 92 cars, of which 29 are motor-cars for overhead trolley-wire alone, and 63 for either trolley-wire or storage-cells. The company has its own station, which has an output of 600 kilo-watts, including reserve. The kilo-watts per mile of track are 10·6, and per motor-car 6·5. According to a report recently issued by the directors of this system the storage-

L

cell is held in great favour. The cost of maintenance has been carefully determined, and comes out on the average at 0·15*d.* per car mile for the year 1896. But allowing for future renewal of plates this figure may be exceeded by 50 per cent.

On the basis of a storage-cell car mileage of 34,000 to 37,000 miles per annum, it is asserted that storage-cell traction costs only 0·4*d.* more than any other system. Sixteen and a half miles of overhead line has been saved by the use of cells, representing about £32,500: taking in addition the maintenance of the overhead line at from 0·037*d.* to 0·063*d.* per car mile, this mixed system only costs 0·2*d.* more per car mile than simple overhead.

There are 110 storage-cell cars being built, and the battery system is to replace the overhead system on all lines. During the first half of 1896 the generating costs averaged 0·66*d.* per kilo-watt hour, and during the second half 0·59*d.* per kilo-watt hour. During November and December the average was 0·54*d.*, the improvement being attributed to the increased use of storage-cells. The entire working cost amounted to 68 per cent. of the year's receipts, giving a net profit of £15,000, after allowing £14,000 for depreciation, from which a dividend of 5 per cent. was declared.

The Use of Storage-Cells in Sub-stations.—The Hamburg lighting and traction system employs batteries in sub-stations for the purpose of reducing the pressure of 500 volts, at which electrical energy is transmitted to them, to the pressure of about 125 volts on each side of the three-wire system of distribution for lighting purposes. Each sub-station contains two motor-generator sets, and a set of storage-cells, giving a potential difference of about 250 volts. The motors are each wound for 125 volts; one motor has one of its brushes connected to the 500-volt negative, and the other motor has one of its brushes connected to the 500-volt positive main. The other brush on each motor can be connected to the outer of the

three-wire system, the cells for charging, or one pole of the generator to which it is coupled. The other two poles of the generators are connected together, and to the centre of the battery and the centre of the three-wire system. Two instances in which storage-cells are used in sub-stations in a pure traction scheme are those of Douglas and Laxey, and Leeds.

Leeds.—The two sub-stations in this system are placed respectively near each end of the line (see Fig. 22), and contain the Chloride Electrical Storage Syndicate's cells. The Roundhay battery, which is on a level considerably above the power-house, contains 250 Chloride R. 15 type cells, having 160 ampere-hours capacity when discharged to an average of 1·8 volts per cell, at the rate of 160 amperes. The Kirkstall sub-station contains the same number of cells of the Chloride S. R. 11 type; but their capacity is smaller, namely, 110 ampere-hours. The charging and discharging of cells is carried out automatically by Dr. J. Hopkinson's switches, which we describe. In each station there are two automatic switches, one for charging cells and automatically cutting out the regulating cells as they become fully charged; the other for keeping the potential difference between the overhead conductor and the rail constant at 500 volts. A front view of the discharge switch is given on the right-hand side of Fig. 56; a back view is given in Fig. 57, which differs a little from the actual switch. Fig. 58 gives a complete diagram of connections for discharge.

The switch proper consists of a circular series of solid gun-metal blocks numbered 0 to 51, between each of which is placed another series insulated from the first, the whole being mounted upon a slate base. Contact is made between any one of these blocks, and the gun-metal ring, R, which forms the terminal of the switch, by means of two metal arms carried by a central spindle, and bearing respectively upon the ring and the contact block. A second ring, R_1,

has a subsidiary brush carried by the main brush, but insulated therefrom, bearing upon it and the circular series

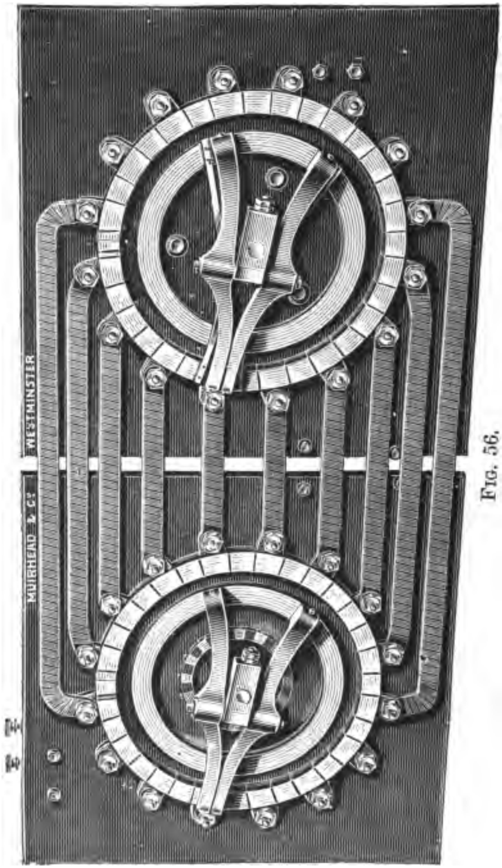


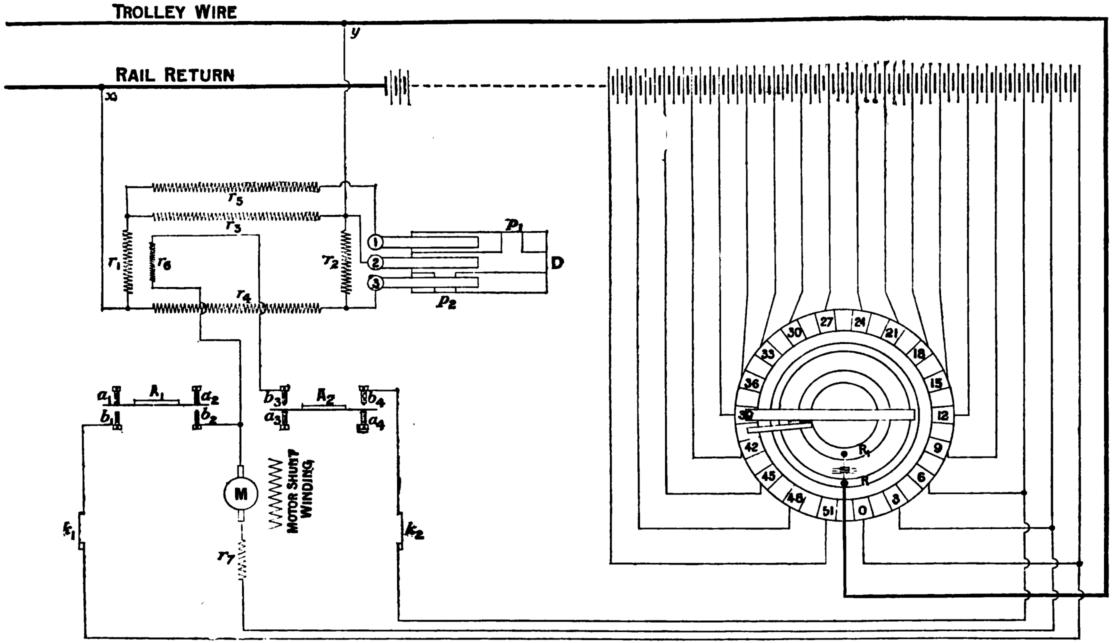
FIG. 56.

of blocks, but does not touch R. Between R and R_1 a polarizing resistance is placed, the object of which is to

carry the discharge current whilst the switch is passing from one block to the next, so that the current shall not be interrupted. This polarizing resistance consists of lead plates in water, and there are two elements in series between the rings. This switch is geared to an electro-motor, M, whose direction of rotation, as well as time of operation, is controlled by a relay, working in conjunction with what is termed a "resetting-drum," D, which is mounted on a spindle of the main switch, and rotates with it. The motor M is a small two-pole machine, with drum

Fig. 57.

armature; its field magnets are permanently excited by the current from one storage-cell—preferably the end one or nearly so, since these are not so much discharged as the others of the battery. The motor armature is excited by a positive or negative current, according to the direction of rotation, from say four or five cells, the number depending upon the speed of operation required and the resistance of the connecting wires between the switch and cells. The object of the relay is to so control the switch that the



TROLLEY WIRE
RAIL RETURN
y
x
r_1
r_2
r_3
r_4
r_5
r_6
r_7
p_1
p_2
D
1
2
3
a_1
b_1
A_1
a_2
b_2
b_3
a_3
A_2
b_4
a_4
M
MOTOR SHUNT WINDING
k_1
k_2
R
R_1
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51

FIG. 58.

potential difference between the trolley-wire and the rails is constant at 500 volts, within about $1\frac{1}{2}$ per cent. on either side. It consists of two small electro-magnets, suspended by springs to prevent vibration (Fig. 59), the protecting case not being shown. Each of these magnets has a

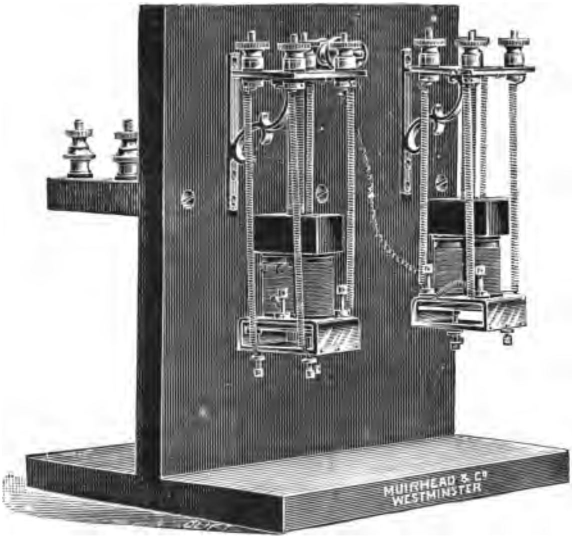


Fig. 59.

small soft iron armature riveted to an aluminium plate, which rests normally against three pointed screws on the cone, slot, and plane principle, so that once these screws are adjusted, the armature, when resting against them, has a perfectly defined geometrical position with regard to the poles of the magnet. These screws are supported by means of a brass box fixed to the bottom of the magnet; and in the right-hand relay magnet they are screwed into the bottom of the box, whilst in the left-hand relay they are screwed into the top of the box. The right-hand armature

rests against its supports by gravity, whilst the left-hand armature has to be held against its supports by the magnetism of the magnet. Since there are three cells between adjacent blocks on the discharge-switch, it follows that three times the maximum potential difference of one cell, say 7·8 volts when fully charged, and the charging current passing through it, is the minimum total variation allowable on both sides of 500 volts, beyond which the switch must act. For instance, if the potential difference between the line and return rises above 504 or falls below 496 volts, the switch must be operated so as to add or subtract cells, until the required 500 volts within the limits mentioned are obtained.

In Fig. 58, r_1, r_2 are the magnet windings of the relay just mentioned, and have resistance 680 ohms; r_3, r_4 are extra manganese resistance coils, of about 11,000 ohms each. The junction between r_1 and r_4 is permanently connected to the rail return, x. The junction between r_2 and r_3 is permanently connected to the trolley-wire, y. Any variation of the potential difference between x and y will produce a corresponding variation in the currents, in the parallel circuits of the relays. The resetting drum, D, is of ebonite, and carries on its surface a copper strip with projections, p_1, p_2, and has bearing upon its surface three brushes, Nos. 1, 2, and 3 respectively. When the switch is central on a block connected to the junction between two cells, the resetting-drum is positioned relatively to the three brushes, as shown in Fig. 58. Brush No. 2 is connected to the junction between r_2 and r_3; brush No. 1 to the resistance r_5, of about 10,000 ohms, which is connected to the junction of r_2, r_3; brush No. 3 to the junction of r_2, r_4. If the drum D turns in either direction from the position shown, it either short circuits the relay-coil r_2, or increases the current in r_1, since it places r_3, r_5 in parallel with one another. But this is for a short interval only, since p_1, p_2 are not very wide. The armatures, A_1, A_2, are

shown in their normal positions; that is, the volts being 500, the magnetizing currents are such that A_1 is held up against its supports, a_1, a_2, the third support not being shown for the sake of clearness; whilst the magnetizing current is not great enough to lift the armature A_2 from its supports, a_3, a_4, the third support not being shown. Suppose the potential difference between x and y falls below 496 volts, the adjustment is such that the armature A_1 drops, thereby completing the circuit between contacts b_1, b_2. The current can now pass from cell No. 1 through a contact-maker, k_1, if closed, to b_1; thence through the aluminium plate to b_2; thence through the armature of motor M through r_7 to the junction between cells Nos. 3 and 4. This current first operates an electro-magnet, of which r_7 is the winding, and removes the brake-block from a light aluminium disc-wheel, which terminates a train of wheels in gear with the main switch, and therefore with the motor M. It then operates the motor in such a direction that the main switch adds cells to the circuit, thereby increasing its potential difference.

When the switch has just reached the next contact-block, and has therefore added three cells to the circuit, the slip, p_1, makes contact with brush No. 1, and raises the armature A_1 against its supports. If now the potential difference be above 496 volts, this armature will remain against its supports, and the motor M is almost immediately braked, since the magnet r_7 is not excited, contact being broken at b_1, b_2. After p_1 has come into contact with the brush, the switch has still a little distance to travel before it is directly upon the block. To ensure this the brake is not allowed to grip the aluminium disc-wheel until the switch is in the middle position, and this is effected by having, in addition to the resetting-drum, a gun-metal disc with slots in it. Against this disc bears a set-screw, which is mounted on an extension of the brake-lever, and it is only when this set-screw comes opposite one

of the slots that the brake is applied, although the current in the magnet winding r_7 has ceased, so that what happens is this :—When the armature is reset and interrupts the current, the mechanism, in virtue of its momentum, is able to travel forward until the set-screw on the extension of the brake-lever comes opposite a slot in the disc. The brake then presses forward on the aluminium wheel and stops the switch. If this device were not used, there is just the possibility that the switch would either overshoot the mark or the brake would pull up the switch before the little brush had again severed contact with the slip p_1. If the switch arrives at contact No. 0, and the potential difference is still too small, the motor cannot act, since k_1 is automatically broken by the switch itself. Take the case in which a sudden removal of load increases the potential difference between x and y; the armature A_2 is immediately raised, and completes the contact between b_3 and b_4. The current can now pass from the junction between cells Nos. 3 and 4 through r_7, through the motor-armature in the reverse direction, through r_6, which is a coil wound on the relay magnet, in such a direction that its ampere-turns augment the magnetizing force already existing, from b_3 to b_4 through k_2 to the junction between cells Nos. 7 and 8. The motor now rotates in such a direction as to subtract cells from the circuit. When the switch reaches the next block, the relay-coil r_2 is short circuited; the armature A_2 falls, and if the potential difference between x and y is below 504 volts, it will remain there; that is, the switch will come to rest, the brake acting as before. The time taken by the switch in passing from one block to the next in either direction can be varied, and is generally about $1\frac{1}{2}$ seconds. In traction work sudden variations of potential difference between x and y have to be dealt with, and consequently the switch must be actuated quickly. The brake is therefore essential with high speeds, in order that it may prevent the switch from overrunning,

owing to the momentum of the moving parts. The coil r_6 is inserted in the armature circuit, in order to prevent the possibility of the armatures A_1 and A_2 making simultaneous contact with b_1, b_2; b_3, b_4, respectively, and this might happen if, when the switch has once started in a given direction, the potential difference between x and y be suddenly varied, so as to tend to reverse the direction of rotation of the switch before the next contact block be reached. The advantage of this form of relay is, that when once the armature begins to move from its normal position, the rapid decrease or increase of the air-space allows it to make sure contact with its supports, which are platinum-tipped. But it requires considerable force to bring the armature back to its normal position, and this is controlled by the switch itself.

The charging switch is similar in construction to the discharging switch, just described, and is shown in Figs. 56 and 57. Its object is to prevent the overcharging of the regulating cells, and this it effects by subtracting cells from the circuit as they become fully charged. Fig. 60 gives a diagram of connections. M is the electromotor, which operates the switch to which it is geared; A_1 and A_2, as before, are the armatures of two relay magnets, of which r_2, r_4 are the magnetizing coils. The armature A_1 falls from its normal position and connects b_1 and b_2, thereby closing the armature circuit. This occurs if by chance the switch gets into such a position that the potential difference between the ring, R, and the rail return falls below 500 volts; the object being to avoid the charging-current passing through the cell or cells in a reverse direction before entering the discharge circuit. The armature A_2 is normally upon supports, a_3, a_4, and the magnetizing coil, r_4, is automatically placed across the terminals of the end three cells which are being charged, by means of two small brushes, c_1, c_2, which rotate with the switch and bear upon a series of small blocks, arranged in a circle, and connected

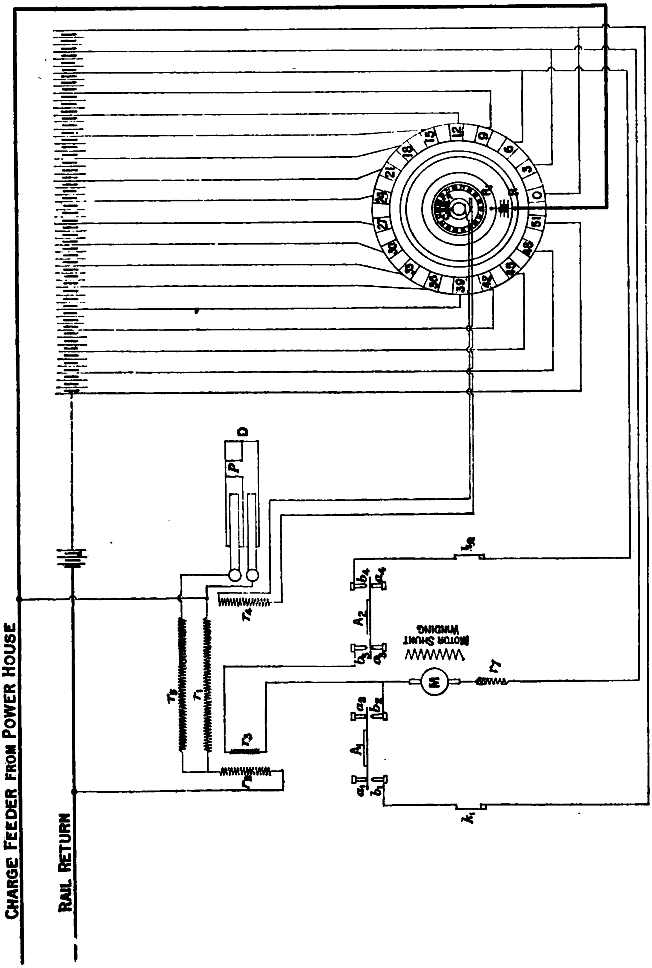

CHARGE FEEDER FROM POWER HOUSE
RAIL RETURN
MOTOR SHUNT WINDING
D
P
M

FIG. 60.

respectively to every third regulating-cell, as in the case of the blocks 0 to 51. If therefore the three end cells are fully charged, the potential difference having risen to, say, 7·8 volts, the armature A_2 is lifted, with the result that the switch moves in such a direction as to cut out three cells. The brushes, c_1, c_2, are so arranged that they break contact with the terminals of the three cells being cut out, just before completing the operation, and then come to rest across the next three cells lower down. At the moment of breaking contact the armature A_2 drops, and if the next three cells are not fully charged, it will rest on its supports until such time as the potential difference has risen to about 7·8 volts, or whatever potential difference the armature is set to lift at. The resetting drum, D, resets the armature A_1 by placing resistance, r_5, in parallel with r_1. The magnetizing coil, r_3, is wound on the left-hand relay magnet, and has for its object the prevention of the two armatures A_1 and A_2, making simultaneous contact with the stops, b_1 b_2, b_3, b_4, which would, of course, short-circuit the cells, Nos. 0 to 6. As in the discharge-switch, two contacts, k_1, k_2, are supplied, so that in no case can the switch overrun the end blocks. The main brush in this switch is the same as shown in Fig. 58, and has been left out for the sake of clearness.

The Use of Storage-Cells on the Car for Lighting Purposes.—An instance of the use of cells on cars for lighting only, is at Bristol. The power-house contains a main set of storage-cells for the cars. These cells are of the Chloride type, the main battery consisting of 55 cells, each capable of discharging about 550 ampere-hours at a six-hour rate, and charged by means of a motor-generator from the 500 volt circuit. The lighting cells for the cars consist per car of two sets of five cells each in boxes. The great advantage of this method of lighting is that the light is steady, and if the trolley wheel becomes detached from the overhead conductor the supply does not fail.

CHAPTER VIII.

ALTERNATE AND DIRECT CURRENTS.

It is well known that the transmission of power by alternate currents can be carried out with great economy when the distance is great. The chief reason for this is the ease with which one can transform from one potential difference to another by aid of the alternate current transformer. It is possible, therefore, to generate currents in the station at low potential with safety and to raise this potential many fold for the line, which can consequently have a small cross-sectional area, thereby reducing its first cost. At the receiving end of the line, another transformer can be placed to reduce the pressure again within safe limits. With direct currents it might be said that the same thing can be done, and with some truth; but direct current dynamos have not been built, and would be costly to build, if they had to work at such potential differences as, say, 20,000 volts. The absence of commutators on the alternate current generator is a great point in favour of alternate currents, since with direct currents and high potentials this becomes a large item in the first cost of the machine.

In large tramway schemes, with the supply from one power-house, the first cost of copper in the feeders becomes great, and one may be justified in reducing this by means of sub-stations containing transforming apparatus. No hard and fast rules can be laid down, as each case must be treated on its own merits, and the justification rests in part with the engineer. In most tramway schemes in Great Britain

where the radius from power-house is of the order of three or four miles, one may say that direct currents need not be deviated from. On the other hand, when the distance gets to eight or ten miles, the alternate current becomes of value. The Central London Railway and Dublin Southern District Tramway are good illustrations of the latter condition, and here alternate currents are employed (see pp. 175, 188).

It will be well to divide this subject into two parts: first, the use of alternate currents in feeder systems, transformation taking place at sub-stations, such transformation producing direct currents for the line; second, the use of alternate currents in feeder systems, the transformation producing alternate currents of smaller potential for the line.

Alternate Currents for Feeder and Direct Currents for Line.—In practice one meets with one, two, and three-phase alternate current machinery, and it will be well to discuss briefly their relative advantages and disadvantages. We have to consider the generation of the current or currents, the transmission of energy by the aid of such currents, and the motor which receives the energy in the sub-station. With regard to generation it can be fairly said that the two or three-phase generator for the size of machine is capable of delivering a greater output than a single-phase generator when what are termed "mixed phases" are employed; but in any case, the choice of one-, two-, or three-phase is not influenced so much by considerations of the generator as by other parts of the system. In either case if the potentials be of the order of 5000 or 6000 volts, stationary transformers would probably be employed; this is the case at Portland, Oregon, U.S.A. But at 3000 volts between the conductors, the three-phase transmission at Dublin (see p. 188) is effected without such transformers; that is to say, the three-phase currents are transmitted directly from the generator to the motor at 3000 volts.

With regard to the line itself, it comes to laying either

a double or triple concentric cable or two or three overhead conductors according as the system is single, or two-, or three-phase. If the system be three-phase the volume of copper required is three-fourths the volume on the single-phase system, but of course there is the extra insulation of one conductor. The advantage of the two- or three-phase over the single-phase really lies in the satisfactory working of large rotatory transformers, which receive such currents and transform them into direct currents. Consider the rotatory transformer; this is a motor-generator, the armature of which receives the one-, two-, or three-phase currents, and also gives from an ordinary commutator a direct current at the required potential. In such a machine, if the alternate currents be single-phase, it is stated * that Professor Mengarini's experience at Rome is all against such machines for large sizes, since they are reported to spark so violently on the direct current commutator, this being due to the varying rate of delivery of energy by the single-phase current, whilst the rate of delivery by direct current is constant. With the two- or three-phase transmission the case is different, as is evidenced by the satisfactory working of the 600 kilo-watt rotatory converters at Niagara and Portland. The General Electric three-phase rotatory converters at Portland are illustrated in Fig. 61. It has been pointed out by Mr. Parshall that reaction of the armature is so small, that a three-phase 500 kilo-watt rotatory converter will carry double and treble this load without the least sparking at the brushes. This is attributed to the more steady delivery of energy by three-phase currents. It is well known that the rate of delivery of work by a single-phase generator, and conversely the receipt of work by a single-phase motor, fluctuates continuously; an inductive load, giving phase-difference between potential and current, returns energy to the system at each half period. With a two- or three-phase transmission

* See the *Journal of the Institution of Electrical Engineers*, vol. xxvi. p. 408.

the rate of delivery of work is constant if perfect symmetry obtains. Mr. Parshall also quotes the case where, without excitation, a 600 kilo-watt rotatory converter maintains synchronism and perfect collection up to 900 kilo-watts. According to the tests at Niagara, the efficiency of a well-

FIG. 61.

designed 600 kilo-watt converter is 96 per cent. on full, and 94 per cent. on half load.

Fig. 62 illustrates a British Thomson-Houston three-phase synchronous motor or generator. In outward appearance it differs little from an ordinary multi-polar direct current generator or motor, except that the usual commutator

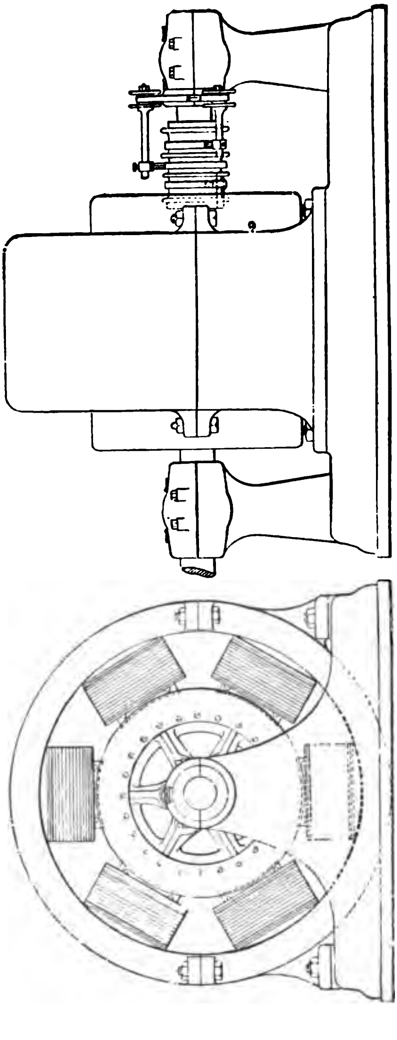


FIG. 62. From *Engineering*.

is supplanted by three plain metal rings on the shaft. The radial poles in motor and generator are excited by direct currents, and the generator armature consists of three windings placed in slots in such manner that the angular distance between them is one-third of the distance between two poles. The inter-connection of these three coils is perhaps best described by considering the methods of grouping three-phase conductors. If we imagine a ring wound as in Fig. 63, which is generally termed the "star grouping," with six coils, 1, 2, 3, 4, 5, 6, equally spaced out and connected, as shown in the diagram, and revolving between two poles of an electro-magnet, then, assuming uniform rotation and uniform field distribution, we may say that E.M.F. induced in coils Nos. 1 and 4 is A sin $\frac{2\pi t}{T}$, where A is the maximum ordinate, T is the periodic time or the time of a complete revolution, and t is the time corresponding to any position of the armature. If the poles be placed right and left, obviously $t = 0$ when the coils 1 and 4 are top and bottom. The E.M.F. in 2 and 5 is A sin $\left(\frac{2\pi t}{T} + 60°\right)$, and the E.M.F. in 3 and 6 is A sin $\left(\frac{2\pi t}{T} + 120°\right)$. The terminals a, b, and c are joined together, and in some cases connected to the body of the armature, as in the Lauffen experiments,* and the terminals d, e, f are connected to three insulated metal rings on the shaft, the brushes bearing on these forming the terminals of the three-phase machine. We see that the currents in

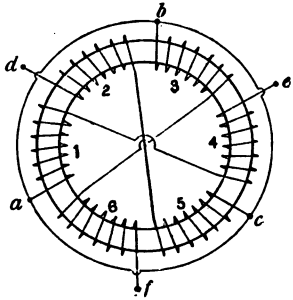


Fig. 63.

* See Thompson's "Polyphase Electric Currents," p. 107.

the line-wires proceeding from *d*, *e*, *f* are the same at any moment as the currents in the respective coils 2 and 5, 3 and 6, and 4 and 1, whilst the potential difference between two lines equals $\sqrt{3}$ of the potential difference of one pair of conductors, the phase being altered by 30°. If the currents be in phase with the potentials—that is, the load be non-inductive, or equivalent to non-inductive—the total power equals twice the potential difference between any two lines into the current in one line, provided everything is symmetrical. If phase difference is introduced, the power factor or ratio of true to apparent watts must be considered. The inter-action of single-phase generators and motors is explained in the *Transactions of the Royal Society*, vol. clxxxvii. pp. 229–252.

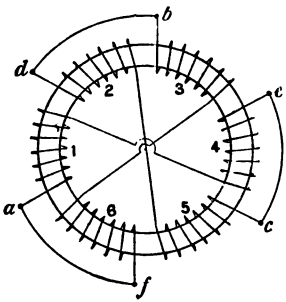


Fig. 64.

In the "mesh grouping," shown in Fig. 64, the coils are cross connected as before; but *af*, *bd*, *ce* are joined together respectively. In this case the current in the line is equal to $\sqrt{3}$ of the current in the armature conductors. The three line-wires being connected to the junctions *af*, *bd*, *ce*, the potential difference between any two lines is the same as the potential difference of the armature conductor between such lines. The power reduces as before, if current be in phase with potential, to twice the potential difference between any two conductors into the current in one line, provided everything is symmetrical. The power factor must be considered when phase-difference between current and potential exists. In actual practice both these methods of grouping conductors are used, and sometimes combinations of the two. One would expect a smaller armature reaction for the mesh grouping for a given line current, but the internal resistance of the armature

for the same volume of copper would be greater. The treatment of two-phase currents is similar to the above. The winding of one-, two-, and three-phase armatures is well set forth in Messrs. Parshall and Hobart's *Armature Windings.*

Alternate Currents for Feeder and Line.—The question as to whether an alternate current received at the feeding-point at a high potential should be transformed into another alternate current at a lower potential, say 500 volts, and as such to be transferred directly to the line and thence to the motors on the cars, naturally depends upon the suitability of such motors for traction work. We have in this case the choice of using either a constantly running synchronous motor on the car, in which case a suitable friction clutch must be used to apply the power to the wheels, or a non-synchronous motor. In the first case, the motor would no doubt work well, and a set of storage-cells on the car would serve for exciting the dynamo, as well as for lighting, but the gear is the difficulty. The second case is the one actually adopted in practice, and then the two- or three-phase system is undoubtedly better. The great drawback of the alternating current in the line itself, if this be single-phase, is the want of a single-phase motor, which has all the good points we find in the direct current, and two- or three-phase motors. If the two- or three-phase system be employed, the motor is satisfactory; but two overhead wires are a necessity, and this introduces complications at crossings. With the slotted conduit system the two conductors and the rail could be used as the three wires in a two- or three-phase transmission, and since all the conductors are near together and parallel, there should not be so much disturbance as is experienced when the overhead conductors are used, since these are near to telegraph and telephone lines. The alternate current has the advantage of comparatively small action on metal underground, which, as we have seen, has been the means of such stringent rules on the part of the Board of Trade in the case of direct currents and rail returns (p. 53).

The Author is indebted to Messrs. Brown, Boveri & Co. for the following particulars of their system at Lugano, Switzerland. This tramway is an instance of three-phase transmission for about $7\frac{1}{2}$ miles from the power-house at Maroggia, where the power is derived from a 300 H.P. turbine directly coupled to two 150 H.P. Brown three-phase generators. The speed is 600 revolutions per minute, and the potential difference is 5500 volts, the frequency being 40 periods per second. These generators are well known, and are of the inductor type. Fig. 65 shows one of these generators with the top half removed. It will be seen that the magnets which rotate consist of four poles on one side of the magnet winding, with four poles on the other, such poles being connected together near the shaft by a concentric circular yoke, on which the exciting coil is wound. The poles on either side have an angular distance between them of 45°, and since there are four like poles on one side there are four complete periods per revolution; that is, since the revolutions per minute are 600, the frequency is $\frac{600 \times 4}{60} = 40$ complete periods per second, as stated. The stationary part of this generator consists of soft iron sheet stampings in the form of rings, which have an internal diameter large enough to clear the poles of the exciting magnets. The conductors are threaded through a series of holes punched out in a circle near the inner edge of the rings; the three phases are produced by dividing the distance between two poles, that is, an angle of 45°, into groups having an angle of 15° between them. The electro-motive forces induced in such groups of conductors must therefore have phase differences of 60°; that is to say, similar electric events, if there be symmetry, happen in the three groups of conductors, but at times differing by $\frac{1}{240}$th second. These generators are each excited by a small dynamo direct coupled to the shaft.

There are several motors connected to the mains

along the line. A transformer station is placed about a quarter of a mile from Lugano, and reduces the pressure to 400 volts, the secondary coils of the transformer being

FIG. 65.

connected to the two overhead trolley-wires and the rails at this point. A bare copper wire, 7 mm. diameter, is laid in the earth to the junction-point at Lugano, to reduce

the drop of potential difference in the rails. The aggregate length of this line is about three miles. The gauge is one metre; the steepest gradient is 6 per cent., and the sharpest curve has a radius of 50 feet. The trolley-wires are 6 mm. diameter. They are 10 inches apart and 18 feet above the rail level. It is stated that no difficulty has been experienced with the working of the line. There are four cars running, each capable of seating 24 persons, and provided with one 20 H.P. three-phase 12 pole motor, connected through single reduction gear to the axle, the ratio being 1 : 4. The maximum speed of the motor is 400 revolutions per minute, corresponding to about 9 miles per hour of the car. The two trolley arms on each car are placed one behind the other at a distance of one yard. The motor is of the inclosed type, with an opening at top for the purpose of examination of the collector rings on the armature and brushes. The stationary portion of this motor receives the three-phase currents from the two overhead trolley-wires and the rail, and for ordinary speeds and starting such currents produce at any moment 12 poles on the inner surface of this part, which, as in the generator, consists of a number of soft iron ring-shaped stampings, with holes punched out near the inner diameter. The conductors are parallel with the axis, and are threaded through such holes. It follows that since there are 12 poles, there are six complete periods per revolution; and since the frequency is 40, the revolutions per minute, if perfect synchronism were obtained, would be 400.

The subject of difference of frequency between armature and rotatory magnetic field is full of interest, and such difference depends upon the load on the motor, the magnetic field, and the resistance of the armature conductors. In working these motors, and starting with the armature running light when it is very nearly in synchronism with the

* See *Electrician*, August 28, 1896.

rotating field, the torque gradually rises as the load is applied until it reaches a maximum with a given difference between the frequencies of the armature and field; any further load brings about a diminished torque, and instability sets in. We have already seen that the maximum power the motor has to develop may be three times the average, and it is, therefore, important to see that the average power is well within the maximum, and of course the motor should work with high efficiency at its average rate. It has been pointed out by Mr. Brown * that under normal working conditions the field of these motors is comparatively weak, and the torque can be considerably increased, since it depends upon the current in the armature and the field by changing the connections from star to mesh-grouping, and without altering the applied potential difference. The armature in these motors consists of a number of soft iron discs threaded on the shaft, and secured to it by a key and end plates. These discs have a series of holes punched out in a circle near the periphery, through which the conductors are threaded. In motors of this size (20 H.P.) such armatures require extra resistance in the circuit of their conductors for starting purposes; but in small sizes, as is well known, the conductors are simply connected together at each end by soldering them into solid copper rings, such conductors and rings resembling a squirrel's cage. In the larger motors, however, the armature conductors, if wound according to the star grouping (Fig. 63), have their three respective ends connected to three insulated metal rings on the shaft. By means of brushes these rings are connected with an external rheostat, which is under the control of the motor-man; such rheostat is shown in Fig. 66, and consists of resistances which can be varied by turning round the vertical spindle in a similar manner to an ordinary controller (Figs. 6 and 7). The truck complete with motor and rheostat is shown in Fig. 67.

* See *Journal Institution of Electrical Engineers*, vol. xxvi. p. 425.

The motor-man has two switches to handle: one of these makes the circuit and regulates the resistance of the armature circuit for starting and stopping; the other serves for totally breaking the supply circuit, or reversing the direction of current when the direction of the motor requires reversal. For higher speeds outside the town the number of poles is reduced on the stationary part of the motor, thereby increasing the speed; also, for increased torque,

FIG. 66.

the connections are changed from star grouping to mesh grouping.

This system has been in operation at Lugano since December, 1895, with satisfactory results, and the novelty of it lies in the use of the induction motor on the cars. We have seen that the three-phase transmission is used in the Dublin tramway feeder system, and there are several instances of long distance transmission for traction work by three-phase currents, notably that at Portland, Oregon,

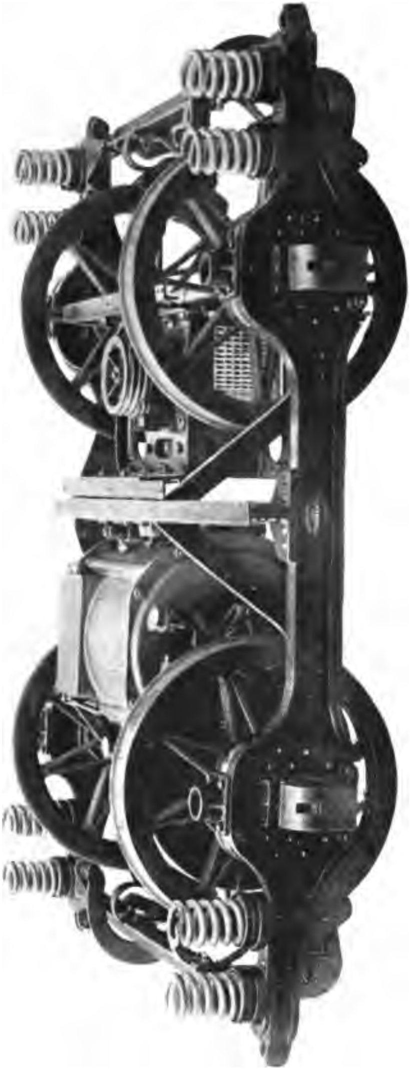


FIG. 67.

U.S.A., but in these direct currents are used for motors on the cars.

In all cases of high tension transmission it is necessary to transform down to a voltage of about 500, in compliance with the Board of Trade regulations and for the public safety. In the transformation, running machinery must be employed if direct currents are to be produced, as we have seen at Dublin; whereas, if alternate currents be employed on the car itself, the transformation can be effected by a stationary transformer with no moving parts, and requiring little or no attention.

Messrs. Brown, Bovri & Co. inform the Author that they are now (June, 1897) occupied with the equipment of the following lines with three-phase traction:—

1. The Gorner-Grat railway near Zermatt. This is a rack railway with a maximum gradient of 20 per cent. The length is about six miles, and the locomotives will be equipped with two motors of 90 H.P. each. Each train is to accommodate 110 passengers.

2. Engleberg railway. This is a line 14 miles long, having but slight gradients for the greater part of its length, and here worked by adhesion. For about two miles there are gradients of 25 per cent., and here a special electric locomotive is attached, working on a rack.

These lines will be at work in the course of about a year.

This firm has just concluded the contract for the equipment of the line from Burgdorf to Thun. This is a standard gauge line, and will carry traffic at ordinary railway speeds; it is to be running in about two years. We see, therefore, that three-phase currents, as applied to the motors on the cars, are making considerable headway.

The Central London Railway.—The electric traction system shortly to be brought into operation on the Central London Railway is at the present time attracting much attention by all persons interested in this work. The contract has been secured by the British Thomson-Houston

Company. The engineers to this railway did not settle the scheme to be adopted, but left this to the competing firms to propose for themselves. The following specification was issued, giving the requirements:—

"CENTRAL LONDON RAILWAY.

"*Electrical Traction Plant.—Specification of General Requirements.*

"1. The work intended to be included in the specification includes the finding of all materials, tools, and labour for the complete manufacture and installation, and, except as regards fair wear and tear, the maintenance for a period of twelve months after the opening of the railway, of all the electrical plant and appliances necessary for working a $2\frac{1}{2}$-minutes' service in each direction, of trains of seven carriages, having a seating capacity of 336 persons, and weighing 105 tons loaded, exclusive of locomotive, over the Central London Railway, at an average speed of fourteen miles an hour, including stoppages at stations.

"2. The said railway consists mainly of two tubular tunnels of 11 feet 6 inches internal diameter, lined with cast-iron, and of enlarged tunnels of similar construction at fourteen stations, and at certain cross-over roads.

"3. The position of the stations and the distances apart, measured from centre to centre of the platforms, are proximately as follows:—

	Yards.
Shepherd's Bush to Holland Park	1,012
Holland Park to Notting-hill Gate	683
Notting-hill Gate to Queen's Road	768
Queen's Road to Westbourne Park	986
Westbourne Park to Marble Arch	1,288
Marble Arch to Davies Street	642
Davies Street to Oxford Circle	699
Oxford Circle to Tottenham Court Road ...	666
Tottenham Court Road to British Museum ...	682
British Museum to Chancery Lane	746
Chancery Lane to Post Office	1,163
Post Office to Bank	828
Bank to Liverpool Street	841

"4. In addition to the preceding length of double line of railway, there is a further length of 1036 yards at Shepherd's Bush from the centre of the platform to the end of the sidings in the depôt, and at Liverpool Street a length of 236 yards from the centre of the platforms to the end of the sidings. The total length of continuous railway over which electrical traction must be provided is 12,276 yards or 7·6 miles, exclusive of cross-over roads at stations and sidings.

"5. The gradients of the line and the general details of the railway, so far as they affect the subject-matter of this specification, are shown on the drawings herewith. [These drawings are not reproduced in this book.]

"6. The contractor shall be deemed to have full knowledge of the Central London Railway Acts, and shall perform all the obligations imposed on the railway company thereby.

"7. All work and materials shall be of the highest class, to the entire satisfaction of the engineers.

"8. The whole of the work shall be completed within eighteen months of the acceptance of tender.

"9. For working the above service of trains, 32 electric locomotives shall be provided of the strongest, simplest, and most efficient type, without gearing or pitch chains, and capable of taking the specified trains over the line at the required speed, and into the depôt at Shepherd's Bush.

"10. The generating plant shall be of ample capacity to furnish power for the working of the railway with only three-fourths of the same in operation, and the remaining one-fourth in reserve. The boilers, high-pressure engines, economizers, dynamos, main and return conductors, insulators, and all other necessary appliances, shall be such as will ensure the highest attainable economy and facility in working and maintenance, and be least liable to breakdowns, so as to secure the safe and uninterrupted working of the traffic at all times with comfort to the passengers,

and freedom from injurious interference with any public or private interests.

"11. The contract will include the construction of all necessary connections with the coal sidings and mechanical stokers in the boiler-house. It will also include the complete fitting up of repairing shops, and the supply of all tools necessary for keeping the whole of the work included in this specification in efficient condition and repair. The buildings, engine foundations, and other masonry works form no part of this contract, but, as far as may be necessary, will be constructed in accordance with the plans and specifications furnished by the contractor.

"12. The locomotive must be provided with compressed air-brakes, but the air-compressed plant is not included in the present contract.

"13. An alternative tender must be submitted for two-minutes' service."

The following is a reported description of the plant to be employed on this railway, which will be installed by the British Thomson-Houston Company.

Track.—This consists of 100 lb. steel rails on heavy sleepers well ballasted : 35 per cent. of the power necessary to accelerate the trains is saved by means of a 3 per cent. rise and fall at each station (see p. 10). The working conductor is in the form of a third rail supplied with ample copper feeders, and means are provided at short intervals to enable the operators in the signal-stations to cut out any section desired. The schedule speed, including stops of 20 seconds at each of the fourteen stations, will be 14½ miles per hour.

The Generating Station.—This is above ground at Shepherd's Bush, and will contain six 1300 H.P. horizontal Corliss engines by E. P. Allis and Co., each directly connected to a General Electric three-phase 5000 volt generator. These are of the stationary armature type, with rotating field, and are intended to give 850 kilo-watts at 5000 volts,

at 94 revolutions per minute, or a frequency of 25 periods per second. The 5100 kilo-watts are to be transmitted from the generators by heavy conductors to a switchboard, from which feeders convey the three-phase current to the sub-stations along the line. In these sub-stations static transformers will drop the potential difference from 5000 to 330 volts, for which the alternating current side of the rotatory converters are wound. The working potential difference of the line is 500 volts. Of the four sub-stations two will contain seven 300 kilo-watt rotatory converters, similar in design to those at Niagara. Only six of these transformers are to be in use at any one time, the seventh being held in reserve. The remaining sub-stations will contain one 900 kilo-watt converter and four 300 kilo-watt transformers. All the transformers are to be of the "air-blast" type; the air, which circulates freely between the core and windings, being driven through by means of a blower.

Locomotives.—The number of locomotives to be constructed is 35. The motors, which are four in number and directly connected to each axle, are of the G.E. 56 type. They are to be worked on the series-parallel control system, and are capable of exerting a draw-bar pull of 14,000 lbs. Each locomotive weighs 35 tons.

Three-phase versus Three-wire for Electric Traction.—The recent discussion of Mr. Baylor's paper before the Institution of Electrical Engineers,* brought forward some very useful information with regard to the suitability of the three-wire system for traction work, and a comparison of it with that of the high potential three-phase feeder systems just described. It appears that two large English firms proposed the three-wire system for this scheme, and the "Americans," as it was put (meaning, it is supposed, the British Thomson-Houston and the Westinghouse Companies), proposed the two- or three-phase systems for feeding at high potential with sub-stations, similar to the Dublin

* See *Journal of Institution of Electrical Engineers*, vol. xxvi.

tramway. So far as the author is aware, there is no English firm which has put down any traction scheme on the three-wire system, and if this be so the system has not been properly tested in the United Kingdom. Without actual experience, it does seem from some points of view that the three-wire system would be a good one to adopt. Professor A. B. W. Kennedy, before a select committee of the House of Commons, in March, 1897, on the Brompton and Piccadilly Circus Railway Bill, which only deals with about 1200 H.P. as against five or six times this amount in the Central London Railway, is reported * to have proposed the three-wire system as being the most advantageous, employing balancing transformers at at least two places on the line. A balancing transformer in a three-wire direct current system consists of two direct current machines, either rigidly coupled together, or the two armature windings are wound on the same core, one being placed between the middle wire and one outer, and the other between the middle wire and the other outer. If, then, the potential differences between the middle wire and the outers are not equal, it follows that, since the machines are the same size, the one runs as a motor, driving the other as a generator, thereby bringing about an adjustment. The process is reversible, and, since the machines are shunt-wound, no reversal of direction of rotation ensues when the change takes place. The proposed Brompton and Piccadilly scheme has a length of about 3476 yards, with five stations; the railway would be placed 50 or 60 feet below the roadway, the service to be a three-minutes' one throughout the day. The generating station is to be placed at Chelsea Creek, which, although some distance from the terminii, is an otherwise eligible site, giving as it does direct communication with the river.

Again, Mr. Snell, after Mr. Parshall's condemnation of the three-wire system in the discussion before alluded to, is still of opinion that the two- or three-phase system has

* See *Electrician*, 26th March, 1897.

not any practical advantage over the three-wire system. Turning to the American side of the question, we find nothing but failure reported on the part of the three-wire system for traction purposes. Mr. Parshall points out, which is perfectly true, that the motor-man must keep his proper time with the other locomotives, and therefore he puts over the controller switch until this is attained, heedless of the current he is consuming. If, therefore, for some reason the potential difference applied to his locomotive is small, he requires more current, and this, again, lowers the potential difference. The effect, therefore, is cumulative, and, naturally, more aggravated the fewer the points of supply on either side of the system. The variation of efficiency with applied potential difference is dealt with at p. 30. In the case of electric lighting on the three-wire system the conditions are different. A diminution of potential difference in the mains has the effect of increasing the resistance of the lamp filaments, which automatically cuts down the current, so that to some extent the remedy is automatic.

Two notable instances of failure on the part of the three-wire system are those of Portland (Oregon), and St. Louis, although others are mentioned in the discussion above referred to. At Portland, where the three-wire system was at first used, the three-phase high potential system has been substituted. The company supplies power for lighting and traction; the power is obtained from the Willamette Falls, about fourteen miles from Portland. In the power-house (Fig. 68) there are three 450 kilo-watt three-phase generators mounted on vertical shafts of Victor turbine wheels, each supplying current at 6000 volts direct to the transmission lines. In the sub-station are placed air-blast transformers, which reduce the potential difference for feeding the low tension lighting system at the city, and also supplying current to two 400 kilo-watt rotatory converters (Fig. 61) used to operate the street railway. This scheme has been in operation since May, 1895, and has

FIG. 68.

demonstrated the suitability of three-phase transmission for railway work. At St. Louis, where there were several hundred cars, the three-wire system, after a thorough trial, Mr. Parshall states, was abandoned, "since it was found that the extra cost and trouble in compensating from hour to hour was of vastly more consequence than the extra cost of copper." With so many cars running on a network of conductors, such as at St. Louis, one would have thought that the conditions were favourable. Referring to the Central London Railway, the same authority states that there are to be operated between twenty and thirty trains, each weighing about 130 tons, and to maintain the average of fifteen miles per hour these trains must have at times a speed of about thirty miles per hour, and must be accelerated at least one foot per second per second. Mr. Parshall estimates that each train may absorb 1000 amperes at times, such figure being based upon actual test, the average output per line not exceeding 3000 amperes. One train, therefore, may absorb about one-third of the total output per line; and this introduces the use of such large balancing transformers, that the three-wire system cannot compete with the three-phase and rotatory feeder system. He estimates that at least three balancing transformers of a capacity of 300 kilo-watts would be necessary, consistent with the Board of Trade regulations as to drop of potential difference in the line.

The Thames Ironworks Company proposed a balancing transformer at each alternate station along the line; that is, six in all, each of a capacity of about one-fifth or one-sixth of the whole output of the station—that is, about 900 or 1000 kilo-watts each. At St. Louis it was found that the neutral conductor had to have as large a cross-sectional area as each of the outers, and under this condition the loss in the neutral conductor and balancing transformers, under favourable conditions, was about equal to the loss of transformation in a well-designed multi-phase sub-station. According,

then, to Mr. Parshall, it comes to a comparison of transmitting energy at 5000 volts and 1000; and if this be so, the high tension three-phase transmission would appear to be the better. He goes on to point out that if the potential difference be suddenly increased, the balancing transformers must at once receive energy to accelerate them, which is a bad condition, since the removal of load from the locomotive should not entail a temporary transference of the load to the balancing transformers. The remarks already made in this book, at page 10, on the efficiency of motors, show how such efficiency depends upon the potential difference of supply, and consequently any system which has a greatly fluctuating potential difference available at the locomotive terminals must necessarily suffer on the whole. We cannot do better than quote Mr. Parshall's own words, as forming the summary of his remarks on three-phase *versus* three-wire systems for electric traction. They are as follows: "I would point out that the three-wire system for traction work is purely in an experimental condition; that it has been tried in practice and proved a failure; that it necessitates the use of commutating machines and sub-stations, the loss in which, and in the neutral conductor, is comparable in magnitude with that in the sub-stations in the multi-phase system; that the advantages of high voltage transmission are lost; that it introduces additional losses in the locomotive, owing to the fluctuation of voltage in the consuming circuit. (I am aware that this variation of voltage may be compensated for by feeders and boosters. Such an arrangement, however, is at the expense of efficiency, and I will not complicate my discussion by taking it into consideration.)" It is to be hoped, however, in view of this difference of opinion between such eminent experts, that the English engineers will hold their own, by bringing to a successful issue a large three-wire traction scheme.

The Use of Cells in a Three-wire System.—The use of storage-cells in sub-stations to be used on a three-wire system

was not discussed at the above meeting. Such cells, if automatically regulated, would remove some of the objections given. The recuperation, so far as resistance of the cell is concerned, is instantaneous, and the automatic switches at Leeds can operate at the rate of eight volts per second, or more if required, when adding or subtracting cells to or from the circuit. See p. 154.

Alternate and Direct Currents and Storage-Cells.—According to a system proposed by Déri,* each car contains an alternate-current motor, a direct-current motor, and a set of storage-cells. The idea is to keep the load on the station as constant as possible by supplying energy at constant, or nearly constant, rate, by means of alternate currents. The direct-current dynamo is a generator when the car requires little energy to propel it, such generator charging the storage-cells. On the other hand, when the car requires considerable energy for propulsion, the storage-cells drive the direct-current machine as a motor.

* See *Electrician*, July 2, 1897.

CHAPTER IX.

EFFICIENCY.

General Remarks.—The efficiency of an electric traction scheme involves many points of importance to the engineer, and finally resolves itself into the question of how, from the best available source of energy, to carry out the scheme with maximum efficiency, having due regard to expenditure of money. In a given time, a certain amount of work is performed by the source, and the engineer, if he is to use this to the best advantage, must consider the losses, if we may so call them, in the different parts of the system, in order to deliver as much energy as possible for the object in view, with the least all-round expenditure. We may conveniently divide our system into the following parts.

First, the conversion of energy delivered in the form of electricity by the power-station or stations to the working conductors. This includes the efficiency of the electric generators themselves.

Second, the distribution of such energy by the system of conductors to the cars or locomotives.

Third, the conversion of such energy by the motors and necessary controlling apparatus into the mechanical energy delivered to the rails.

A full discussion of the first division involves important questions of average efficiency,* division of plant, spare plant, and the proportion of total power used for purposes other than that delivered in the form of electricity to the conductors of the system. One can readily understand

* See Dr. E. Hopkinson, *Proc. Inst. Civil Eng.*, vol. xci. p. 207.

what a wide subject this is when one considers the many ways in which energy is procured for the purpose of driving the electric generators in the power-house. We have instances of power transmission over long distances in order that water-power may be turned into good account; and in such a scheme the efficiency of this system becomes of much importance, since it has to be considered whether the first cost of turbines, generators, land-lines, and motors, with their continuing cost, is to be less than the employment of steam-engines in the power-house, involving the cost of coal, water, etc. The whole subject of water turbines is of great importance, and is dealt with in works specially devoted to the subject. It may be mentioned that from 75 to 80 per cent. is an efficiency to be obtained with turbines of fair size and good construction. The governing of such turbines is an important question, for if the load be suddenly removed, and racing occurs, the generators coupled to such turbines get severely strained, and may break down. All these are points to be carefully considered. The requirements of the plant used in electric traction are in some respects different to those in ordinary electric supply systems, on account of the sudden fluctuations in the demand for power. If steam be used, for instance, it is of extreme importance that the engine should have sufficient momentum to maintain the speed nearly constant for variations of the load, and the engine should be well governed. The class of electric generator, too, is different in some respects to the generator usually employed in electric supply central station work. The fluctuations, which occur very rapidly, render it impossible to adjust the brushes of the generators for each change of load, and they must be fixed. It is well known that carbon brushes are well suited to varying loads, but copper is also employed in traction work, when the brush is supplied with what is generally termed a carbon "tip;" that is, a small plate of carbon which bears on the commutator just in front of the main copper brush, and has the effect of

suppressing the sparking; but, for satisfactory working, armature reaction must be comparatively small. Large machines of the ordinary two-pole type have, it is well known, great armature reaction, and this would seem to be the reason why they should be superseded by the multi-polar type; otherwise the copper on the magnet windings, owing to the necessary great air-space, becomes excessive. Armature reaction can be reduced by splitting the field magnets (see p. 14). There is no doubt that for large units in traction work the multi-polar type has special advantages. It is lighter and cheaper to make for a given output in watts, and a given speed of rotation, and, on account of the subdivision of the field magnets, the armature reaction is comparatively smaller, thereby giving greater satisfaction on account of the diminished sparking with load variations. The subject of relative weights of bi-polar and multi-polar dynamos has been touched upon in the *Journal of the Institution of Electrical Engineers*, vol. xxvi. p. 127. There is no doubt that the introduction of steel into dynamo building has had an important effect upon the development of the multi-polar type, for good castings can now be obtained, which have a permeability equal to the best wrought iron.

The efficiency of the prime mover and dynamos can only be properly dealt with by considering the average effect. Let a curve be drawn which gives the relation between the rate at which energy is being delivered by the source (be it coal, or water in motion, for instance) and time. Let another curve be drawn giving the relation between the rate of delivery of energy in the form of electricity to the system of conductors, and time. Then the areas bounded by each of these curves between the ordinates corresponding to any two times, and the base line, give respectively, for the intermediate time, the total energies delivered to and by the power-house as a whole, and their ratio gives the average efficiency required. The instantaneous efficiency

may fluctuate greatly, but the engineer must strive to make the average approximate as nearly as possible to the maximum. In electric supply systems the load curve tells us the rate at which work is done by the station, and one of the chief difficulties is to so arrange the plant that, considering first and continuing costs, the station may be worked with a maximum economy. The load curve for a traction station may have fluctuations (see Fig. 75), but the rate at which energy is delivered is, for, say, 14 hours per diem, on the average more constant, and therefore the average supply may more nearly approximate to the maximum capacity of the station. It is well known that in the case of electric supply for lighting, the bulk of the plant installed is only brought into requisition at those hours of the day when the demand is great, and of course storage will reduce the engine plant required. There is no doubt but that traction schemes lend themselves to greater economy, owing to the greater proportion of the 24 hours during which the full power of the station is required; that is to say, the average is more equal to the maximum, and greater economy of production consequently results.

An important question is the combination of electric lighting and traction plants, and it is, perhaps, unfortunate that electric traction has come to the fore in this country after electric lighting; for, as a general rule, one may say that electric lighting plants may not be suitable for traction, whereas traction plants might be suitable for electric lighting. It may therefore be desirable to design electric-lighting plants which will be able to deal with traction schemes if required, so that the two can be combined. The lighting and traction schemes at Rome and Hamburg are good examples of such a combination (see pp. 131, 146).

The subject of power production is a very wide one, and includes water power, steam power obtained from coal and refuse destructors, and gas-engines.

The second division involves the form of conductors to

be used, whether they be feeders forming a simple distribution, or a three-wire or three-phase system.

The third division is dependent, not only on the motor or motors employed, but also upon the variations of applied potential difference, and the controlling apparatus (see Chap. II.).

The actual methods employed under each of these headings are numerous, and experience only can show the best to be adopted. The Author considers it best to discuss a few representative systems, rather than enter upon a general statement.

Dublin.—The two sections of electric tramway under the control of the Dublin United Tramways Company are those of the Southern and Clontarf Districts. The following short description gives some points of importance in connection with the Dublin Southern District Tramways. The line has a length of $7\frac{3}{4}$ miles of girder rail, 76 lbs. per yard, which, with the exception of two short lengths, is double throughout, and the gauge is 5 feet $2\frac{3}{16}$ inches. The design is due to Mr. H. F. Parshall, consulting engineer to the British Thomson-Houston Company, by whom the whole of the work has been carried out. The power-house contains three Babcock-Willcox boilers of 250 H.P. each, working at a pressure of 140 lbs. per square inch. Vicars's stokers, driven by an electro-motor, supply the fuel to the boilers. The scrapers in a Green's economizer, as also the three throw-pumps for the feed water, are driven by shunt-wound electro-motors at 500 volts. The feed-pumps are capable of delivering 16,000 lbs. of water per hour, and mild steel ring main 8-inch steam-pipes are used. The engine-room at present contains four Willans compound condensing two-crank engines, each of 150 B.H.P., working at 380 revolutions per minute with 140 lbs. per square inch steam pressure, but capable of developing 175 horse-power each for short times if necessary.

The dynamos are coupled to a three feet fly-wheel pulley

on each engine by belts. There are two British Thomson-Houston 100 kilo-watt four-pole generators, compound wound to give 500 volts at full load; and two 120-kilo-watt three-phase generators, which, at 600 revolutions per minute, or 30 periods per second, give from 2300 to 2500 volts. The power-house is situated about half a mile from the Dublin end of the line. There are two sub-stations, one at Blackrock, about $3\frac{1}{2}$ miles from the power-house, and the other at Dalkey, at the other end of the line, and distant about seven miles from the power-house. Each of these sub-stations contains two synchronous three-phase alternating-current motors, each direct-coupled to a four-pole generator, giving, at full load, 120 amperes at 500 volts, and connected to the overhead trolley wires and rail return. A few turns of the conductor leading from this generator are wound on the magnets of the synchronous motor to compensate for the reaction of the motor armature upon its field. These motors are run up to speed, and synchronized by means of the 500-volt generators, which are temporarily run as motors from the 500-volt circuit. The commercial efficiency of such motor-generators is stated to be 83 per cent. at full load. The Board of Trade regulations with regard to three-phase high tension transmission on this line are as follows (see also Appendix, p. 233).

"The electrical pressure between the conductors in any electric line, or between any such conductor and the earth, shall not in any case exceed 3000 volts."

"All electric lines laid for the purpose of supply to transforming stations on the 'three-phase system,' shall have their conductors arranged concentrically, the outer conductor being efficiently connected with earth at the generating station, but insulated at all other points; and the thickness of insulation between the several conductors of any such electric line shall not be less in parts of an inch than the number obtained by dividing the number expressing

the maximum electrical pressure, in volts, by 20,000. No such electric line shall be brought into use unless the insulation of every part thereof has withstood the continuous application, during one hour, of twice the maximum pressure to which it is intended to be subjected in use."

At Dublin the car bodies are mounted upon Peckham standard extension trucks. Both the car bodies and frames and the trailer-cars were built by Messrs. George F. Milnes & Co. of Birkenhead, and the principal weights and dimensions are given below, from which it will be seen that the total weight of the passengers on the cars might be about 8·2 tons, and on the trailers about 5·76, making in all 14 tons of passengers; that is, for the motor-car and trailer with a full complement of passengers, we have a grand total of about 22 tons.

MOTOR-CAR.

	ft.	ins.
Outside length of car body	16	8
Total length over platforms	27	2
Extreme width of car body	7	1
Height of platforms above rails	2	2
Height of top deck above rails in centre	9	4
Wheel base	6	0
Diameter of wheels	2	6
Weight of car body and frame	6720 lbs.	
Weight of truck	4480 „	
Total weight		5 tons

Seating capacity in saloon, 24; on top deck, 29.

TRAILER-CAR.

	ft.	ins.
Outside length of car body	14	9
Total length over buffers	23	9
Extreme width of car body	6	10
Height of platforms above rails...	2	0
Height of top deck above rails	8	10
Wheel base	5	6
Diameter of wheels	2	6
Total weight of car		3 tons

Seating capacity in saloon, 24; on top deck, 29.

Each motor has a single reduction spur gearing, 4·78 to

1, between its shaft and the car axle, and is stated to be able to exert a force of 800 lbs. at the rim of a 33-inch driving-wheel at a speed of eight miles per hour (see Figs. 14 and 15). The two motors per car can therefore exert a force of 1,600 lbs. at this speed. The weight of each motor complete is 1,455 lbs.; of which 715 lbs. is taken by the axle. The motor is stated to have a maximum commercial efficiency of 80 per cent.

Efficiency of System of Conductors.—Fig. 21, p. 62, gives a diagram of the conductors at Dublin. A is the power-house at Balls Bridge, B and C are the sub-stations at Blackrock and Dalkey respectively. Consider the three-phase transmission between A and B. There are two triple concentric cables in parallel, the two outers being to earth at the station. The effective area of one conductor is 0·0938 square inches, and the resistance 1·75 ohms. The kilo-watts delivered to this feeder at A are stated to be 261;* that is, 87 per line. The maximum potential difference between the two wires is 3000 volts, which is the maximum allowed by the Board of Trade (see regulations just quoted, and Appendix, p. 233). The apparent watts are $2 \times 3000 \times 60$, since 60 amperes is the current in each line; and since the true watts are 261,000, the power factor would appear to be 0·72. The rate of dissipation of energy in the feeders due to ohmic resistance and current $= 3 \times 1{\cdot}75 \times (60)^2 = 18{,}900$ watts, and this is 7·25 per cent. of the maximum, which is 261,000 watts. The fall of potential between A and B is about 100 volts. Of the 242,100 watts delivered at B, a portion is transmitted by a feeder to C, and the rest is transformed into direct current at 500 volts for the line at, say, 83 per cent. efficiency. Next consider the transmission of power between B and C. One triple concentric cable is used; the area of one conductor is 0·0469 square inch, and the resistance 4·05 ohms. The power delivered to the feeder at B is shown as

* See *Engineering*, 5th and 12th of June, 1896, Fig. 11, p. 771.

$3 \times 27 = 81$ kilo-watts. The amperes per line are 20, giving about 80 volts fall of potential between B and C. The rate of dissipation of energy in the feeder due to ohmic resistance and current $= 3 \times 4{\cdot}05 \times (20)^2 = 4860$ watts. The power given to the feeder at B = 81,000 watts, so that 6 per cent. is lost in this part of the transmission. Since the apparent watts are $2 \times 2818 \times 20 = 113{,}000$, the power factor is about $\frac{81}{113} = 0{\cdot}72$. We have, therefore, 76,100 watts delivered to the synchronous motor at C, and at 83 per cent. efficiency, we get 63,200 watts delivered to the line, which, at 500 volts, gives 126 amperes. Return to sub-station B, the total watts delivered by the concentric cable are 242,000; and 81,000 of this goes on to C, the difference, 161,000, goes to the synchronous motor to be transformed directly, at 83 per cent. This gives 134,000 watts to the line, which, at 500 volts, gives 268 amperes. The whole system as a feeder delivers 197,200 watts to the line in return for 261,000. Therefore, its efficiency as a feeder is equal to about 76 per cent. Take the cost of power at £10 per annum per horse-power. Then, if the rate of supply were constant, we clearly waste in this system, as a feeder, energy at the rate of 86 H.P.; under this heading the annual charge will be £860. Other incidental expenses are wages of attendants and running expenses in the sub-stations as a part of the feeder system. The amount for these per annum, when added to the £860, should, in order that the whole expense may be a minimum, be equal to the interest on the first cost of the system as a feeder, plus the depreciation of the same. The weight of the copper in the concentric feeders the Author estimates at about 15 tons.

We have now to get the efficiency of the whole system as a means of conveying energy from the power-house to the cars. Beyond the power delivered to the line as above, we have that delivered directly from the power-house to the

line. The power-house is assumed near enough to the line to neglect the loss in the connecting mains. We want also the dissipation of energy in the trolley wires and rails. Suppose on each line there are five trains between B and C, three between A and B equally spaced out, and a train each at A, B, and C. Allow 20 amperes per car. Take the distance B, C. Then considering the half of this, and adopting the same method of procedure as on p. 61, $n = 3$, $r = 0{\cdot}111$ ohms, since there are $2n$ intervals between B and C. The watts dissipated $= 0{\cdot}111 \times (40)^2 \times \{(\frac{5}{2})^2 + (\frac{3}{2})^2 + (\frac{1}{2})^2\}$ $= 1550$. Twice this gives 3100 as the total rate of dissipation of energy between B and C in the trolley wires and the parallel feeder. Similarly, between A and B, since $n = 2$, and $r = 0{\cdot}166$, the watts dissipated $= 0{\cdot}166 \times (40)^2 \times \{(\frac{3}{2})^2 + (\frac{1}{2})^2\} = 664$. Twice this gives 1328, so that the total = 4430 watts. The rail might have a resistance of 0·0099 ohms per mile for the double track. We note that the maximum drop in the rail might be about two volts. Further, the watts dissipated in the rails may be neglected. We have then, if we assume the power-house supplies $120 \times 500 = 60{,}000$ watts direct to the line, a total of 321 kilo-watts supplied from the power-house. Of this we may say 68·4 kilo-watts are dissipated in conductors and sub-stations: then 253 kilo-watts are delivered to the cars. The total efficiency, as a system for conveying energy from the power-house to the cars, is 79 per cent., taking the figures as here given.

The Clontarf section has a length of about three miles with 15 motor-cars, and presents a notable contrast to the Southern District so far as plant is concerned. Fig. 69 shows a sectional elevation, and Fig. 70 a plan, of the power-house. The units adopted are three British Thomson-Houston 150-kilo-watt multi-polar generators directly coupled to McIntosh and Seymour condensing engines fitted with automatic cut-off gear. Provision is made for two more such sets when necessary. No sub-stations are employed,

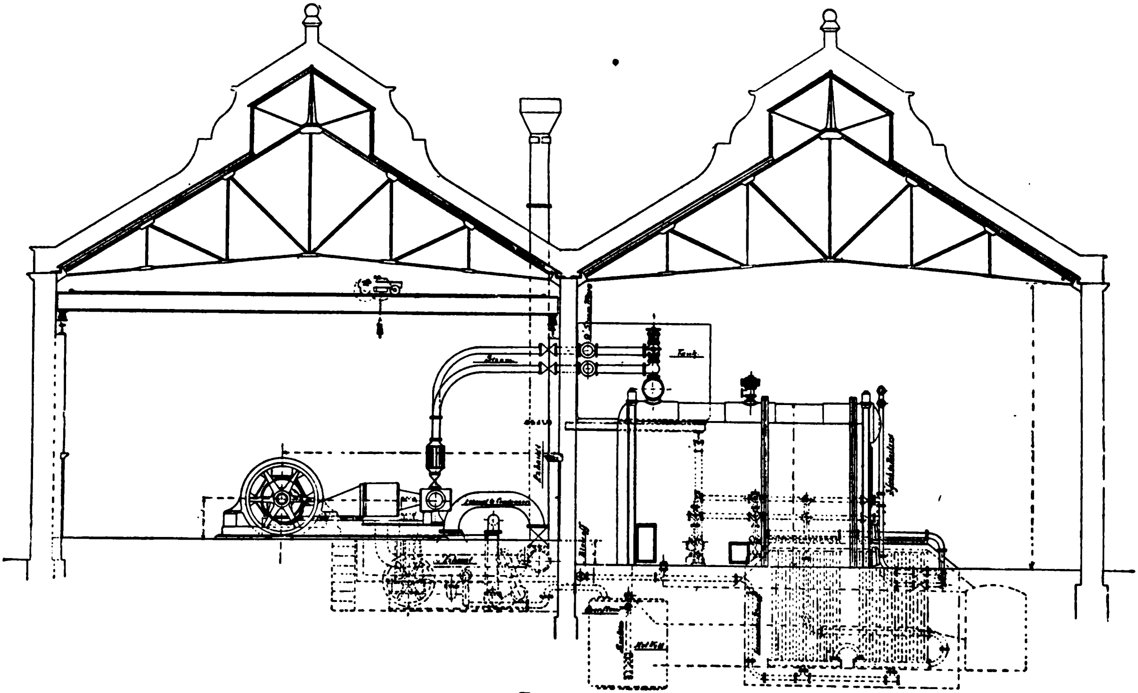


FIG. 69.

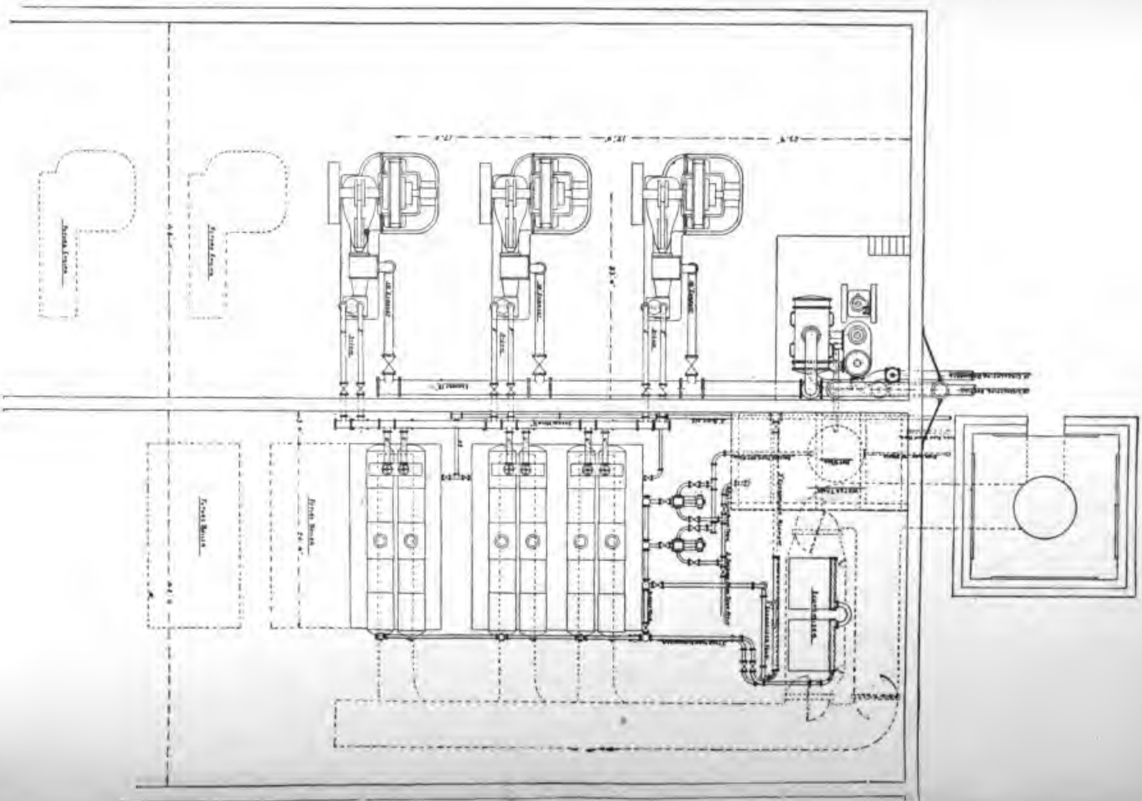


FIG. 70.

and only direct currents are used, the potential difference being 500 volts.

Leeds.—The following is a short description of the electric tramway scheme at Leeds. The line is about seven miles long, with a double track of girder rail, 100 lbs. per yard, and overhead conductors, each 0·4 inch diameter of hard-drawn copper, carried on steel tubular poles 120 feet apart. The gauge is 4 feet 8½ inches. This system has been designed by Dr. J. Hopkinson, F.R.S., the consulting engineer, and has been carried out under his direction. Work was started in August, 1896, and cars commenced running on the 2nd day of August, 1897. The power-house is illustrated in plan in Fig. 71, and is situated about 700 yards from the centre of the line, and contains at present two 400 H.P. Lancashire boilers by Messrs. Clayton, Son and Company, 30 feet long by 8 feet in diameter, shown in full lines. A Green's Economiser and Bennis mechanical stokers are used. There are, at present, two horizontal compound condensing engines, shown also in full lines on the plan, and made by Messrs. Fowler & Co., of Leeds, each capable of delivering at the dynamo pulley, by rope transmission, 400 H.P., with a steam consumption of not more than 21 lbs. per brake horse-power. The fly-wheel of each engine has a diameter of 15 feet, and weighs 19 tons. Each engine drives a pair of Greenwood & Batley two-pole dynamos, coupled together on one base plate. Each dynamo gives 550 volts 200 amperes compound, and 600 volts 200 amperes shunt, at 450 revolutions per minute; so that one pair, if working as above, would deliver 230 kilo-watts, or 308 H.P., to the system. A differential test carried out with a pair of these machines shows that at full load they have each a commercial efficiency of 95·2 per cent. Fig. 22 gives a diagram of conductors in the system. There are two battery stations at C and C′, situate respectively about 5000 and 4600 yards from the power-house. Each battery is charged and

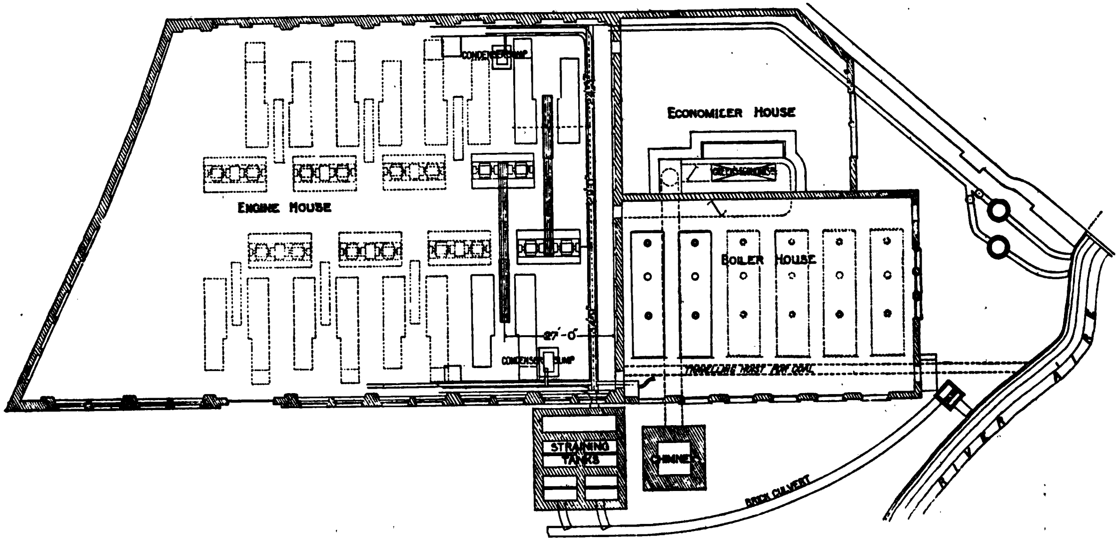

ECONOMIZER HOUSE
ENGINE HOUSE
BOILER HOUSE
CONDENSER PUMP
CONDENSER PUMP
27'-0"
STRAINING TANKS
CHIMNEY
BRICK CULVERT
RIVER AIRE

FIG. 71.

discharged automatically. The switches, of which we give a description in Chap. VII., maintain the potential difference between the line and the track constant at 500 volts, and cut out cells, when charged; but provision is made for the charging feeder never to be placed below the discharge feeder on the cells. The Roundhay battery is at a considerable level above the power-house, and is equipped with 250 Chloride Company's cells, each capable of discharging 160 ampere-hours at the rate of 160 amperes without undue drop of potential. The Kirkstall battery has a capacity of 110 ampere-hours, the rate of discharge being 110 amperes.

The contractors must maintain the battery for the first year without charge, and thereafter at the rate of 8 per cent. on contract price as long as the Corporation shall require.

There are 25 cars made for the contractors, Messrs. Greenwood & Batley, by Messrs. Milnes & Co., of Birkenhead, and mounted on Peckham trucks (see Fig. 34). There are also some trailers. The motor-cars are each supplied with two single reduction motors, constructed by Messrs. Greenwood & Batley.

Efficiency of System of Conductors.—In the diagram, Fig. 22, A is the nearest point in the line to the power-house; B, B′ are feeding points; C, C′ are the battery substations. The feeders to the points A, B, and B′ consist of double concentric cables, each conductor having 0·34 square inch cross sectional area. The inner conductor is connected to the trolley line, whilst the outer is connected to the rails. The single feeder to C′ has 0·25 square inch sectional area, and the single feeder to C has 0·17 square inch cross sectional area. From the power-house to A, B, and B′, the mains are laid in earthenware conduits, having a separate compartment for each feeder, and provision for extension, whilst between B and C, and B′ and C′, the feeder is laid in an earthenware pipe. Assume that each car takes 15 amperes as the average current—and we may be justified in doing this with a system of this magnitude. Then the currents might be as follows:—

Feeder.	Current in amperes.	Resistance of feeder in ohms.	Watts dissipated in feeder.
A	60	0·102	367
B′	60	0·305	1,100
C′	90	0·65	5,270
B	60	0·305	1,100
C	90	0·56	4,540
	360		12,377

Twenty-five cars, at 14 or 15 amperes per car, give about 360 amperes, which, at 500 volts, give 180,000 watts to be delivered to the cars. Neglecting for the moment the rate of dissipation of energy in the trolley wire and rails, which we can safely do, we require 180,000 watts to be supplied to the line. The battery stations have, on our assumption, to deliver 45 kilo-watts each, and we assume they do this at 80 per cent. efficiency. We lose in the battery 22,400 watts, which, added to 12,377, gives, as a total, 34·8 kilo-watts. The efficiency, then, of this system of feeders, under the above assumed conditions, when delivering 180 kilo-watts, is 84 per cent. If we allow £10 per horse-power per annum, we have a continuing cost under this head of £460 per annum, to which must be added the cost of supervision and annual running expenses in the sub-stations as a part of the feeder-system, and this whole amount should be equal to the interest on the first cost of mains, batteries, and switches, and depreciation, in order that the whole may be a minimum.

According to the assumed conditions, we dissipate energy in the trolley wire at the rate of about 740 watts; the loss in the track we neglect; so that the efficiency of the whole of the conductors and batteries between the power-house and the cars, and under the above assumed conditions, practically remains at 84 per cent.

The Author estimates the weight of copper in the feeders at about 27 tons.

The Author is not prepared to enter upon the first costs or depreciation of the plant either at Dublin or Leeds. The following points, however, have struck him with regard to these two systems, which are of similar magnitude. At Dublin (on the Southern District), two distinct kinds of apparatus are used, namely, high-tension alternating currents at 3000 volts, combined with direct-current machinery working at 500 volts. At Leeds the direct-current at 500 or 600 volts only is used; but batteries require careful attention. The power-house at Leeds is more favourably situated with regard to the line than at Dublin in its present state. At Leeds the weight of copper in the feeders is about 1·8 times that at Dublin; but we have seen (p. 55) that the cost of conductors and their laying is not to be judged from the copper alone. At Dublin there is the cost of the sub-stations and rotary transformers, and at Leeds there are the batteries to be considered. Batteries certainly give very great security, for they are not only able to meet at once heavy demands, but, for a time at least, would keep some cars running, and would be able to do the shunting on occasions when perhaps the plant is not running. It must also be remembered that the efficiencies above deduced are so deduced under assumed conditions. Their average values are not discussed.

Efficiency of Locomotives and Cars.—We have seen, in Chap. II., how the efficiency of motors and controlling apparatus can be calculated under given conditions; but, in actual working, the important question is not what the efficiency is at any moment, but what its average is over a certain time. This, for a given motor, is affected by the maximum speed allowed, the schedule of time, the frequency of stopping and starting, the load, and the resisting force. The definite stopping-places on a railway, no doubt, conduce towards economy of working, as compared with the frequent stoppages on a tramway; and the further apart the stopping places are, the greater is the economy. Let a curve be

drawn giving the relation between the watts supplied to the locomotive, or car, in terms of time plotted horizontally. The area of this curve between any two limits, with regard to time, gives in suitable units the actual work done upon the car in that time, and can be expressed in Board of Trade units if desirable. Let a second curve be drawn, giving the relation between the watts actually delivered by the car to the rail, having time plotted horizontally. Then the area of this curve between the same two limits, gives the actual work done upon the rail by the car in the same time. The ratio of this last area to the former is the average nett efficiency of the car between the limits of time considered.

The interesting series of curves given by Mr. Siemens, and alluded to in Chap. II., refer to the locomotives supplied to the City and South London Railway, and give the volts, amperes, and speed as taken on the locomotive itself at short intervals of time during the journey. From the product of volts and amperes we have the rate at which work is done on the locomotive at any time. These products are plotted in terms of the time. The revolutions per minute of the armature are given, since we know the speed and diameter of the driving-wheel. We have seen (p. 21) that the revolutions per minute $= \frac{E}{I} \times \frac{60 \times 10^8}{4m}$; this enables us to find E, since I is known from the characteristic curve, and we know C. Therefore, the rate at which the motors do work, EC, is known at any moment. But we want the rate at which they do work on the rails themselves. Assume, as before (p. 22), that the rate of dissipation of energy due to wind, bearing, and brush friction, magnetic hysteresis and eddy currents in the armature cores, amounts to 1500 watts in the two motors, and that it is constant. Then subtract from EC, at any moment, 1500 watts, and plot the resulting difference in terms of time. A curve drawn through these points

gives us a good approximation to the rate at which work is done on the rails themselves. It is necessary to consider over what lapse of time we want the average efficiency. Do we want it during the time of one-half, or the whole of the journey? It is of interest to obtain the average efficiency during the time between the successive stopping-places, and also to see what are the variations as well as the nett result. Two sets of curves (Sheets I. and II.) have been treated in this manner, and give 75 per cent. as the average efficiency for the round journey, starting from the City station and returning to the same. The locomotive weighs $13\frac{1}{2}$ tons, and the carriages, with passengers, 21 tons. The total length of the line is 5550 yards, and since there are six stopping-places, the average distance between each is 1110 yards. Table X. gives a summary of the results obtained from Sheets I. and II.

TABLE X.

	Sheet II.	Sheet I.
Number of passengers	34	29
Total weight of train, in tons	36·5	36·2
Total Board of Trade units supplied to locomotive	5·394	5·378
Total time of journey in minutes	15·5	14·7
Average speed, including stopping, in miles per hour	12·2	12·9
Board of Trade units per mile	1·71	1·71
Board of Trade units per ton per mile	0·0469	0·0472

The whole of the eight sets of curves, making four complete round trips, have been treated in the same manner, and the average efficiency of the locomotives comes out at about 70 per cent.

In the tests (Sheets I. and II.) the average current for the journey is about 50 amperes, at about 420 volts; but, for the whole series of tests, the volts varied from about 400 to 460, which, as we saw in Chap. II., has an important

effect on efficiency. The maximum amperes were from 130 to 140. Most of the acceleration is accomplished in half a minute from starting, during which, on account of the low net efficiency of the locomotive, most of the energy is dissipated in the resistance coils on the car. The average maximum speed is 18 miles per hour. We see from the summary of results that the Board of Trade units per mile for an average speed of $12\frac{1}{2}$ miles per hour is 1·71, whilst the Board of Trade units per ton per mile is 0·0469. Compare this with tramway working. Take Montreal *; here, at an average velocity of $7\frac{1}{2}$ miles per hour on an ordinary tram line, the consumption is 0·26 Board of Trade units per mile per ton, the maximum load being, perhaps, 10 tons, as against 36 on the City and South London Railway.

The motors on the City and South London Railway have their armatures directly connected to the axle of the driving wheels. In ordinary tramway work one sees almost universally the motor geared to the car axle by spur gearing. It is, of course, advantageous to reduce the weight as much as possible when the whole load is on the driving wheels. Therefore the geared motor has this advantage, that it is lighter, and runs at a higher speed; but the net efficiency is not necessarily greater, since the gearing has to be considered. At the present time the efficiency of good spur gearing is stated to be over 90 per cent., but the Author has not made direct tests to prove this. It could be accurately determined by taking two motors on an undertruck, coupling their axles together, and obtaining a direct measurement by running the system so arranged differentially, preferably making all the measurements electrical, as shown in *Engineering*, March 24, 1893. Of course the dynamo has this advantage over the steam-engine, for instance, that its efficiency does not depend solely upon frictional variation. The electrical dissipation of energy in the motor becomes less with the load, and therefore the efficiency is maintained

* See *Proceedings Inst. Civil Engineers*, vol. cxxiv. p. 287.

at a higher figure for the corresponding smaller loads. At the present time only one reduction by gearing is usually used in tramway work, and, in a few instances, like the South London Railway locomotives, the motors are driving directly on the axle; two gears seem to have been entirely superseded by the single reduction. The ratio varies in actual practice, but is generally from 1:3 to 1:5. Steel is probably the best material for the pinion, although cast-iron and phosphor-bronze give good results. Cast-iron is used for the spur-wheels. As we have seen in the consideration of the City and South London locomotives, Chap. II., the series-parallel control certainly raises the average efficiency, since a greater range of speed can be obtained with high actual efficiency, and this is of extreme importance where motors have to run at greatly varying speeds.

CHAPTER X.

THE POWER-HOUSE.

The sudden fluctuations in load to be dealt with in traction work call for extra strength in engines and dynamos, as well as very good governing with regard to speed under quickly varying demands. Especially is this the case in small schemes, where the average demand differs considerably from the maximum, and where a larger relative plant is consequently required. The conditions of working are such that the plant must be able to run for long periods of time, and, therefore, in the power-house special care must be taken in the choice of engines and dynamos. The indicated horse-power per car running is dependent upon the size of the undertaking, since, if this be large, the average demand at the station terminals does not differ so much from the maximum. In small plants, therefore, we find the indicated horse-power per car high; then provision has to be made in small plants for extra demands, owing to fêtes or any general holiday, such occasions calling for a much greater supply, since the cars are crowded, and perhaps extra ones running; whereas, in large schemes, any extra demand becomes of less importance. In a system of about the size of Dublin or Leeds, the brake horse-power of steam-engines is about eighteen to twenty per car, not making any allowance for power used for other purposes in the station, such as stokers, economizers, pumps, etc. This figure must be approximate, and can only be got at by a careful

consideration of any actual undertaking. In August, 1896, there appears to have been generated on the German Tramways an average of 15 kilo-watts per motor car. Allowing 80 per cent. for efficiency of engines and dynamos, we get 25 I.H.P. per motor-car. In January, 1897, in the United Kingdom, the average kilo-watts per motor-car for tramways comes out at about 19. This would correspond to 32 I.H.P. per motor-car, if 80 per cent. be allowed. Dawson gives, at page 217 of "Electric Railways and Tramways," the variation of indicated horse-power per car in terms of the total number of cars running at 35 to 15, as the total number of cars varies from 1–5 to 25–50.

The subdivision of plant is a very important question; that is to say, the size and number of units and reserve machinery for a given scheme. At Leeds the number of engines at present are two, each of 400 brake horse-power, one being spare. At Dublin, on the Southern District, there are four engines of 150 brake horse-power each. At Bristol there are four engines of about 230 H.P. at one-third cut off, which is the most economical load.

On the City and South London Railway, in February, 1893, from 60 to 67 per cent. of the total steam produced was absorbed by the electric generator engines.

Boilers, Engines, Turbines, etc.—The subject of boilers demands a separate work to itself. This problem is to a great extent the same as that which has to be dealt with in electric lighting stations. The water tube and Lancashire types are much favoured by engineers. The only mention we can make of boilers will be when describing an existing station; and the same remark applies to turbines. Economisers and mechanical stokers are almost always used nowadays in traction stations.

A full discussion of the steam-engine is not to be attempted in this book. The whole question as to high and low speed, horizontal and vertical, direct coupled, and belt or rope driving, depends greatly upon the size of the

units, the actual floor space available, and the engineer designing the undertaking. The important points in any engines for traction work are great strength, since the load fluctuations are severe and sudden, great momentum to compensate in some measure for such fluctuations, and a powerful governor, which must be automatic and quick acting.

The average load is, for fairly large systems, from 0·6 to 0·7 of the maximum, and steam engines should therefore work at maximum efficiency at about 0·6 or 0·7 of their maximum power. The engine should also be constructed to stand considerable overloading. The whole subject of speed regulation cannot be too well considered, and especially is this the case in alternate current working, where the generators have to synchronize.

Governors.—The large McIntosh and Seymour compound engines have a governor acting on both cylinders.

Figs. 72 and 73 represent a centrifugal governor as made by this firm, and the following is the maker's own description :—

It consists of centrifugal weights which vary the point of cut-off by revolving the governor eccentric upon the shaft, and is designed so that the centrifugal force of each weight is very great, making the governor exceedingly powerful. These forces are opposed in a direct and frictionless manner by a plate spring through hardened steel pins resting in cups at each end, so that there is no friction or pressure due to these forces upon the pins upon which the weights turn. Dash pots are provided, which give stability to the governor. Great care is taken in the mechanical construction throughout. The pins are made of tool steel, hardened and ground, turning in bushes of hard phosphor bronze, with provision for lubrication. The governor can be adjusted as to sensitiveness by changing the length of the pins between the centrifugal weights and spring, these pins being arranged to telescope for this purpose. The speed

is regulated by changing the weight of bushings in the centrifugal weights. This governor can be adjusted to give practically perfect regulation, without any tendency whatever to race under a sudden decrease of load.

The Willans' centrifugal governor with throttle valve

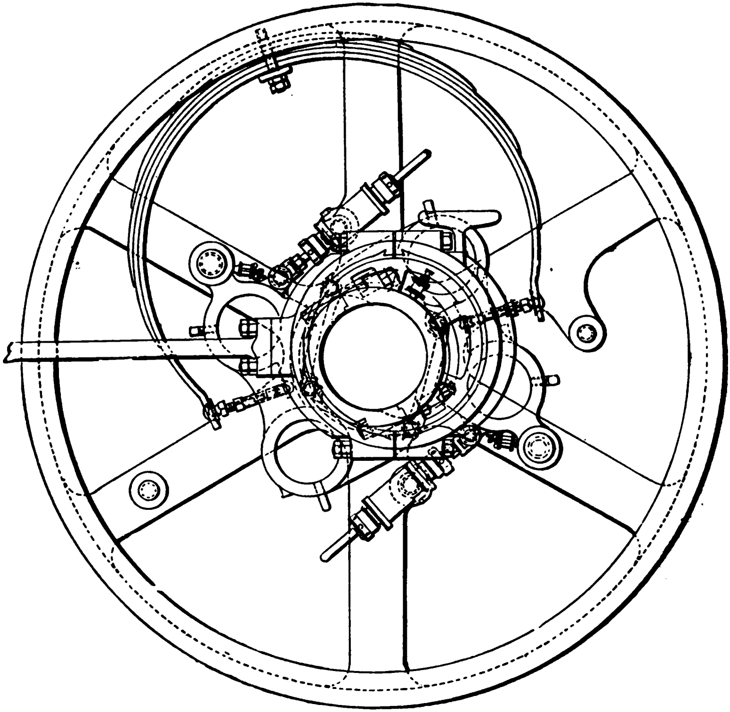


Fig. 72.

and variable expansion gear is used in traction plants. Referring to a Willans direct coupled set at Stockwell, Mr. McMahon, in the discussion of Mr. Raworth's paper before the Institution of Electrical Engineers,* on the "Generation

* See *Proceedings*, vol. xxvi. p. 483.

of Electrical Energy for Tramways," states that the governing was about the most perfect he had ever seen in a traction station; the variation of speed being not more than four or five per cent. at the most. The total output of the set was 250 amperes at 500 volts. With the engine running light,

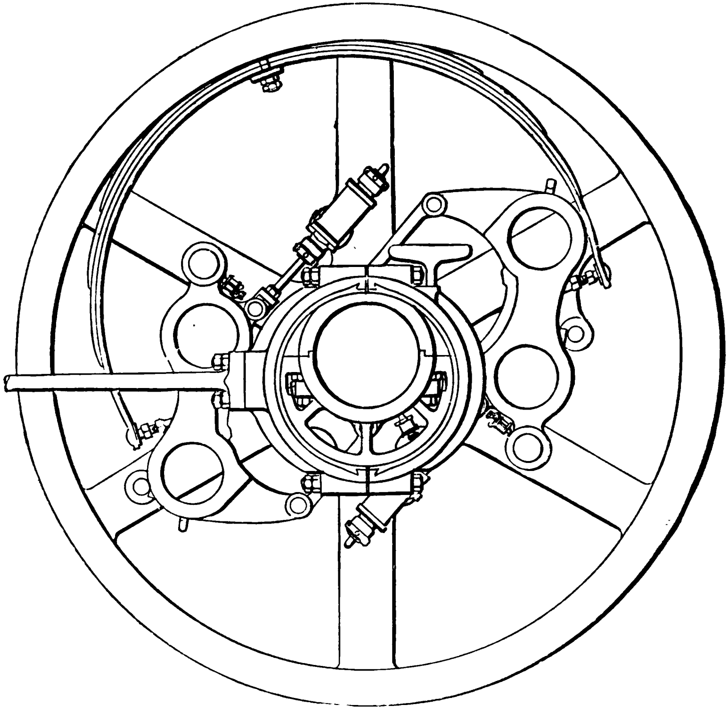


FIG. 73.

and full load instantly thrown on, the cut-off in the high-pressure cylinder changed instantly from 0·15 to 0·6, with a speed variation of about four per cent. The description of this governor is too long to give here, but it is well worth studying. Of course fly-wheel action is included in

this effect. Fig. 74 gives two curves relating to a Willans engine, showing variation of speed per cent. and load in electrical horse-power.

It should be here mentioned that there are other good governors, for instance, the Proel, but space does not allow of a description of these.

Fly-wheels.—The following is an endeavour to ascertain

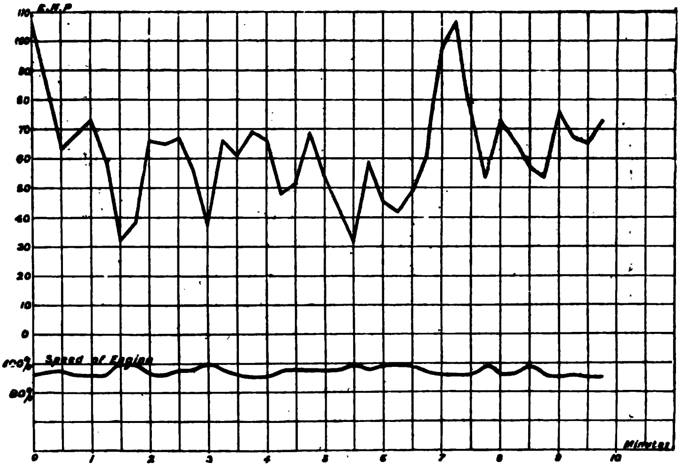


FIG. 74.

on what basis the fly-wheel for a given load should be constructed according to modern practice in traction work.

The Author has taken Table XI. from the list of Messrs. McIntosh and Seymour, which refers to their standard compound railway engine. This is a horizontal type engine fitted with piston valves, and a central governor which works directly on the valve rod, and is stated to regulate the speed of the engine within two per cent. for all changes of load from zero to full.

TABLE XI.

Type A condensing engines.

Indicated horse-power.	Range of initial pressure in lbs.	Revolutions per minute.	Fly-wheel—Two wheels per engine.			Weight of engine in lbs.
			Diameter in inches.	Face inches.	Weight in lbs.	
90	90–110	260	66	12·5	2300	11,500
215	90–110	210	82	18·5	4500	29,500
400	110–120	195	88	26·0	7000	46,750
500	110–130	175	108	32·0	8000	66,500

If w be the angular velocity of a wheel, then any particle of mass m at radius r is revolving at velocity $v = rw$, and its energy is $\frac{1}{2}mv^2$, or, if preferred, $\frac{1}{2}mr^2w^2$. The energy of the whole wheel is therefore $\Sigma(\frac{1}{2}mv^2) = \frac{1}{2}w^2\Sigma(mr^2)$; or the sum of the second moments of inertia of all the particles multiplied by $\frac{1}{2}w^2$.

Taking the table just given, we assume that the radius of gyration for the rim of the wheel is one inch less than the external diameter would give; further, we assume that the weight of the rim is 85 per cent. of the total weight of the wheel, and that this is acting at the above assumed radius. From this radius, the mass, and the normal speed, we deduce the energy $\frac{1}{2}mv_0^2$ in foot-pounds, v_0 being the mean normal velocity in feet per second. Assume now that a five per cent. diminution in the speed has been effected. Then we deduce $\frac{1}{2}mv_1^2$ where v_1 is the mean velocity of the rim at this reduced speed; $\frac{1}{2}mv_0^2 - \frac{1}{2}mv_1^2$ is the work in foot-pounds delivered by the wheel to the shaft. The time of this delivery in minutes is taken to be the difference of the initial and final revolutions per minute, divided by the mean of the two revolutions; and

therefore the rate in foot-pounds per minute will be the quotient of these two quantities. It is further assumed that 85 per cent. of the indicated horse-power is delivered at the terminals of the dynamo, which is being driven by the engine. This has been reduced to foot-pounds per minute, and the whole of the figures are given in Table XII. A comparison shows that, under the assumed conditions, each engine fly-wheel is able to deliver energy on the average at the same rate as the dynamo, and the two wheels combined would deliver the same average energy for twice the time. Of course this does not mean that if the engine could be instantaneously robbed of steam the fly-wheels would maintain the load on the average for double this time, since there would be the friction in the engine to consider as well as the dynamo efficiency. It seems, therefore, according to the practice of Messrs. McIntosh and Seymour, that the fly-wheels are constructed to operate as above described. The variation of speed during one revolution is not here discussed.

TABLE XII.

v_0	v_0^2	$\frac{1}{2}mv_0^2$ ft.-lbs.	v_1	v_1	$\frac{1}{2}mv_1^2$ ft -lbs.	$\frac{1}{2}mv_0^2 - \frac{1}{2}mv_1^2$ ft.-lbs.	Ft.-lbs. per minute.	Assumed ft.-lbs. per minute at dynamo brushes.
72·6	5270	159,600	69·0	4760	144,000	15,600	304,000	252,000
73·3	5370	319,000	69·5	4830	287,000	32,000	596,000	604,000
73·2	5360	495,000	69·4	4820	445,000	50,000	950,000	1,120,000
80·9	6550	693,000	76·7	5890	623,000	70,000	1,320,000	1,400,000

The limiting velocity for the rims of cast-iron wheels varies from 80 to 100 feet per second (see Unwin's "Machine Design").

In the engines at Leeds, which have to deliver 400 H.P. to the dynamo pulley, the piston speed is not greater than

490 feet per minute, with a boiler pressure of not less than 115 lbs. nor more than 120 lbs. This piston speed corresponds to about 100 revolutions per minute. The fly-wheel has a diameter of 15 feet and weighs 19 tons. Comparing this roughly with McIntosh and Seymour's 400 indicated horse-power engine, we see that the revolutions per minute are 195 as against 98, and the two fly-wheels combined have

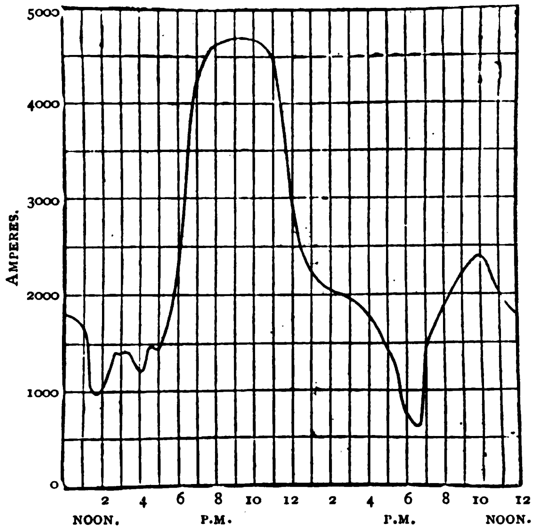


FIG. 75.

a weight of 14,000 lbs. and a diameter of 88 inches, as against 42,560 lbs. and a diameter of 180 inches for the Leeds engines.

Size of Unit.—The size of units to be employed in traction plants deserves special attention, since the experience gained in electric lighting does not wholly apply. The mean load-curve of a traction station is of course not constant, as is shown by the curve in Fig. 75, which refers to

the Philadelphia traction power station, and Mr. McMahon's remarks,* with regard to the City and South London Railway, agree with the same statement. At the same time there is no doubt a wide difference between the curve of a traction station and an electric lighting station; that is to say, in traction, the engineer is warranted in putting in larger and fewer units than in electric supply, on account of the more constant average load and greater proportion of the twenty-four hours during which it is experienced. Dawson gives Table XIII., which refers to the proposed relation between the total indicated horse-power and the number and size of units (see "Electric Railways and Tramways," p. 218).

TABLE XIII.

Maximum indicated horse-power required to work road.	Number of engines recommended.	Indicated horse-power of each engine.
200	2	200
400	3	200
600	3	300
1,000	3	500
1,500	4	500
2,000	4	750
5,000	6	1000
10,000	8	2000

As a recent example in actual practice we may look at the Bristol Station (see also Dublin, p. 187; Leeds, p. 195).

Fig. 76 gives a sectional elevation of the Bristol electric tramway station. It exhibits the best practice at the present time, and was designed by Mr. Parshall, and carried out by the British Thomson-Houston Company. It contains four Adamson Lancashire boilers, working at about 160 lbs. pressure; the length of the boilers is 30 feet, and the diameter inside 7 feet 6 inches, fed with Vicar's mechanical stokers and Green's economizers, driven by an

* See *Journal of Institution of Electrical Engineers*, vol. xxvi. p. 483.

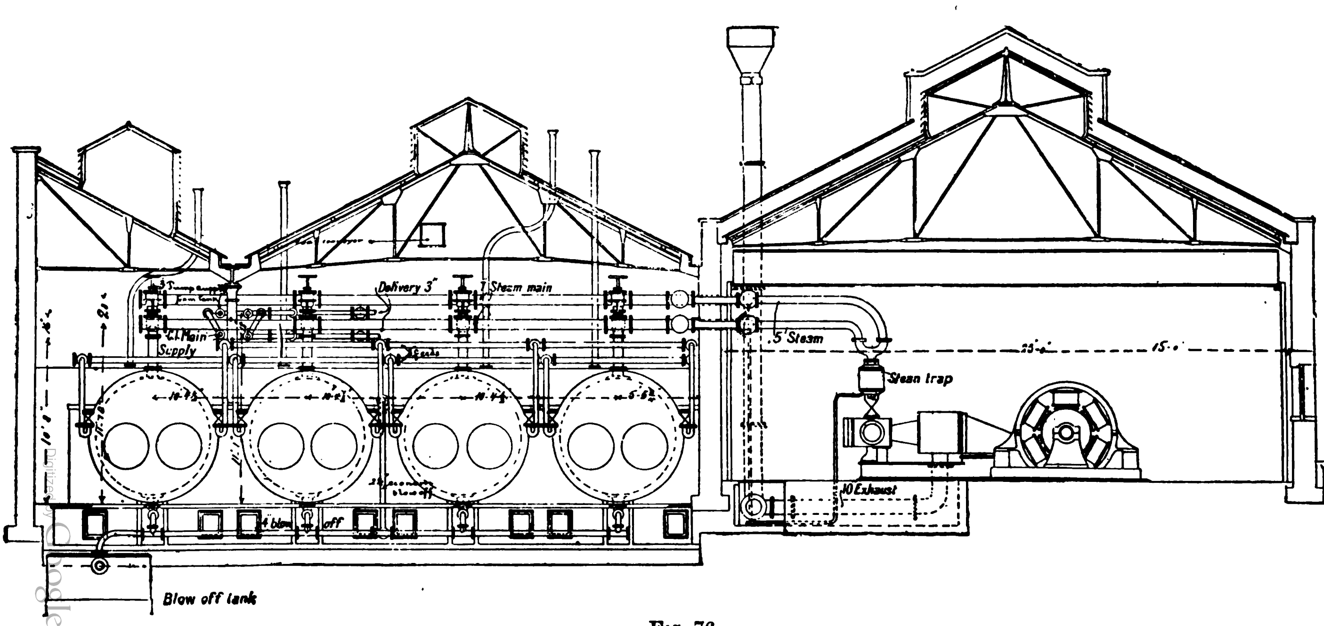

Delivery 3"
7 Steam main
C.I. Main
Supply
.5 Steam
Steam trap
10 Exhaust
4 blow off
Blow off tank
15.0
23.0
10.8
21.6

FIG. 76.

electromotor. Two feed-pumps, capable of supplying 16,000 lbs. of water per hour to the boilers, are also driven by electromotors. The engine room contains McIntosh and Seymour engines of the horizontal type, running at 200 revolutions per minute. The total weight of each engine is 46,000 lbs., and the weight of each fly-wheel is 4500 lbs. There are four of these engines direct coupled to four 150-kilo-watt six-pole generators with toothed armatures, having 95 per cent. efficiency at full load, and 88 per cent. at quarter load. The guaranteed speed regulation of these engines is two per cent. between no load and full load. The governor we have already illustrated and described. There are 22 motor-cars on this line, each capable of seating 18 persons inside and 26 outside, and these carry storage-cells for lighting purposes. The charging of these cells is carried out by means of a motor-generator, having an output of 135 volts and 230 amperes.

Direct Coupling.—There is no doubt that direct coupling between engines and dynamos has advantages over other modes of driving, and its suitability is amply demonstrated both in America and in Europe. At the same time authorities differ. A notable instance in the United Kingdom of conversion from rope to direct coupling is Bristol; and there is little doubt but that for sizes of generators over 100 kilo-watts output direct coupling is the best. It is certainly more economical to do away with belts and rope, since energy and the cost of such belts are thereby saved, and at the same time the floor space is diminished.

Steam-engine Tests.—The testing of engines and boilers or turbines, if water-power is used, is of importance, since the efficiency is specified, and the engineer must satisfy himself that it is attained. The test imposed upon the contractors by Dr. J. Hopkinson in the case of the Leeds steam-engines is as follows :—

"The engine shall be run with a Buss tachometer attached, and the maximum load of about 400 brake horse-power

shall be thrown on and off as many times as the engineer may consider desirable; the speed shall at no time be less than five per cent. below the normal speed, or more than five per cent. above the normal speed. If the engineer sees fit, the engines may further be tested as follows: The engine will be run with its dynamo machine fully loaded so as to receive about 300 H.P., and the engine will be indicated from time to time and the mean taken. The engine will be run with its dynamo machines light, and the engines will be indicated. The difference between the two indications shall be taken as the net power of the engine. The steam supplied during four hours or thereabouts to the engine and its jackets shall be determined. If the condenser or circulating pumps are driven by a separate engine, the steam supplied to such engine shall be added thereto. The steam supplied shall not be more than 21 lbs. per net horse-power."

The Generator.—In America and Europe the generator for traction work has received special attention at the hands of the designers. In America the multi-polar machine is almost universally used at the present time, and for large sizes there is no doubt that this is the best type to adopt. Fig. 77 illustrates one of these large direct coupled generators in motion.

The subject of slotted or toothed and smooth core armatures in generators is of great interest and importance (see Chapter II.), and although the toothed armature is largely used, it is not universal. The Leeds generators have smooth cores, and the City and South London Railway motors and generators are other instances; yet in America the toothed armature is almost universally used, and there seems little doubt but that traction motors at any rate will have toothed armatures for reasons already discussed (p. 15). The subject of armature reaction and brushes has been discussed in Chapters II. and IX.

The testing of dynamos should receive special attention

FIG. 77.

from the following points of view—first, sparking; second, maximum rise of temperature; and third, efficiency.

Since the brushes must be fixed, it follows that, to properly test the machines for sparking, the load should be rapidly varied, and this during a run of at least six hours' duration, although in traction work the machines sometimes have to be run for days together.

The maximum temperature to which a machine will rise if running at full load requires careful attention. The most stringent temperature limit in dynamos is usually that known as the Admiralty temperature specification. This states that the maximum rise of temperature of any part of the dynamo above the atmosphere shall not exceed 70° Fah. after six hours' run at full load. The taking of temperature by means of thermometers is not, of course, the best method, but it is the most practicable. The temperatures specified are to be taken on thermometers in the usual way by placing them on the parts to be examined, and protecting the bulb from air draughts. The average temperatures may be taken by the measurement of resistance.*

The subject of efficiency of dynamos is best dealt with by the differential test, if two similar machines are available, and this is the case in most power-houses. The differential test was devised by Drs. J. and E. Hopkinson, and given in the *Philosophical Transactions of the Royal Society*, 1886. It can, however, be carried out in such a manner that all the measurements are electrical. This is advisable when a third dynamo, or storage battery, is available to supply the losses in the system. There are two methods by which this can be carried out—(*a*) by placing a battery or dynamo in series with the two armatures; (*b*) by placing it in parallel with the two armatures. This subject is dealt with in *Engineering*, March 24, 1893. The Greenwood and Batley generators at Leeds have (June, 1897) been tested differentially by means of method (*a*) above mentioned

* See *Electrician*, August 28, 1896.

(see p. 195). The differential testing of alternators is set forth in the *Philosophical Transactions of the Royal Society*, vol. 187, 1896, A, pp. 229–252.

Switchboards.—The arrangement of switchboards must be such that extension is easy, and in keeping with the rest of the station. This has given rise to the panel system of switchboards, whereby the various switches, complete for a given purpose, can be mounted on a panel of slate or marble and placed in line with those already installed. This makes the arrangement very flexible ; large firms supply standard panels for dealing with feeders, generators, etc.

The over-compounded machine is largely used in traction

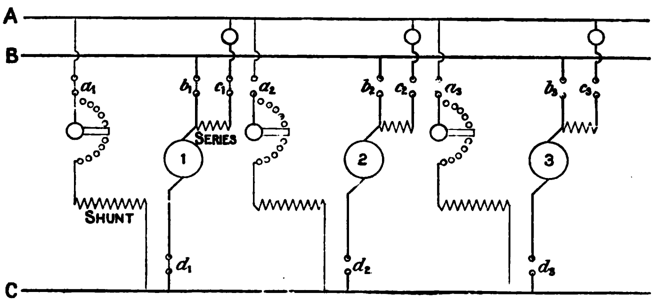


FIG. 78.

stations, as is well known ; that is, at full load it gives, say, 550 volts, and on open circuit 500 volts, the difference being due to the extra magnetization due to the series and shunt turns, since the potential difference across the shunt increases with the load, and the current to the external circuit passes through the series turns. It is therefore necessary to study the throwing of compound machines in parallel with others running in the station. In Fig. 78 let A C be the positive and negative omnibus bars of a system of feeders in the station, and 1, 2, 3, compound dynamo, of which No. 1 is running ; it is required to place No. 2

in parallel with No. 1 ; close a_2 and excite the shunt of No. 2 machine across the mains; then close the main switches b_2, c_2, thereby placing the series turns of No. 2 in parallel with those of No. 1. The machine must now run at such a speed that the potential difference between its terminals is equal to that between A and C ; the switch d_2 can then be closed, placing the machine in the circuit. The extra shunt resistance serves to adjust the field, so that at normal speed the proper potential may be obtained before closing d_2. Further than this, provision is generally made for running the machines half compounded for the feeders of shorter length, in which case the series coils are placed in parallel, there being two separate windings; for fully compound, they are generally in series. In the case where batteries are employed, it is necessary to operate the machine as a simple shunt when charging, and since the potential difference must be large, it follows that when working compound the shunt magnetizing force must be relatively small, so that when working shunt it can be increased to give the proper potential difference. If the limits of potential difference between simple shunt on full load and compound on open circuit are too great, the machine will either be working too low on the characteristic curve, in the latter case, giving rise to instability, in the sense that small variations of speed and changes of temperatures will greatly influence the potential; or, in the former case, the shunt coil will have to supply an unusually large magnetizing force, making the machine expensive to build. The change from simple shunt to compound is easily effected by short-circuiting the series turns.

There are various devices for breaking the circuit automatically if the current gets too great, and these are preferable to the ordinary fuse, since they act quicker, and are not so troublesome to replace. The breaking of the main switch first and the subsequent separation of carbon cylinders, which are easily replaced and take the spark, is one

method ; the magnetic blow out is another. This is due to Professor Elihu Thomson; and consists of a substantial pair of electrodes which take the sparking as just mentioned; but these are placed in a strong magnetic field produced by the current itself, such field immediately blowing out the arc formed.

Fig. 79 gives a view of the British Thomson-Houston automatic circuit breaker, and Fig. 80 a diagram of connections for the same. When the circuit is closed, the current flows through a solenoid T to a contact block M, through the yoke Y to the block M_1, and thence to the outside circuit. If the current exceeds a predetermined value, depending upon the tension of the spring S, Fig. 79, the armature A is attracted, lifting the lever L. The yoke Y is immediately drawn down from the contact blocks M, M by a powerful spring, and the current then passes through the coils B,B (Fig. 80), and upper contacts C,C. The current produces a powerful field between the poles of an electro-magnet, of which B,B are the magnetizing coils, the contacts C,C being directly under the influence of such field. When the bridge-piece P ultimately severs contact between C,C, the spark is at once suppressed.

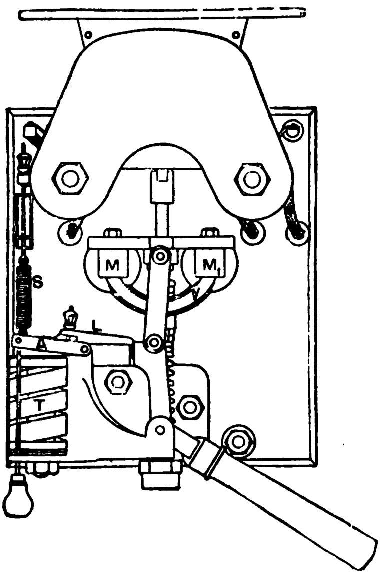


Fig. 79.

For the breaking of a shunt-circuit the device above mentioned can be adopted; but by another method the shunt coil is momentarily placed in parallel with a non-inductive resistance, through which the excessive potential

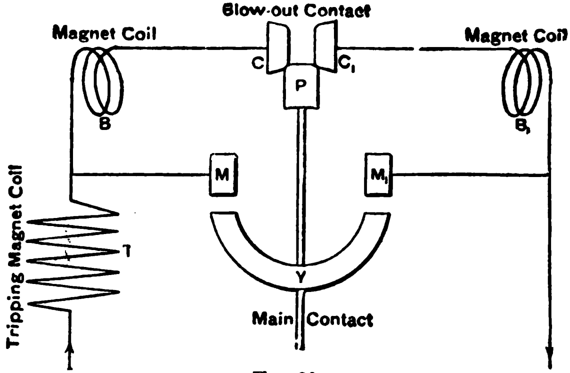


FIG. 80.

difference can send a current until such potential difference has subsided (see *Engineering*, December 11, 1892).

The Leeds switchboard is shown in Fig. 81, and is an example of a modern traction board for direct currents. The drawing of the switchboard should be studied in conjunction with Fig. 22. Provision is made for handling four dynamos, each being so arranged that it can be coupled full compound, half compound, or simple shunt; but close parallel running, as shown in Fig. 78, is not in the first instance to be arranged for.

The first four panels are devoted each to one machine. On each are mounted an automatic magnetic cut-out, a double pole switch, a Weston ammeter, a Ferranti ampere-hour meter, and shunt resistance regulator. An arrangement is provided whereby all the cut-outs can be simultaneously put back if more than one should fall at the same time.

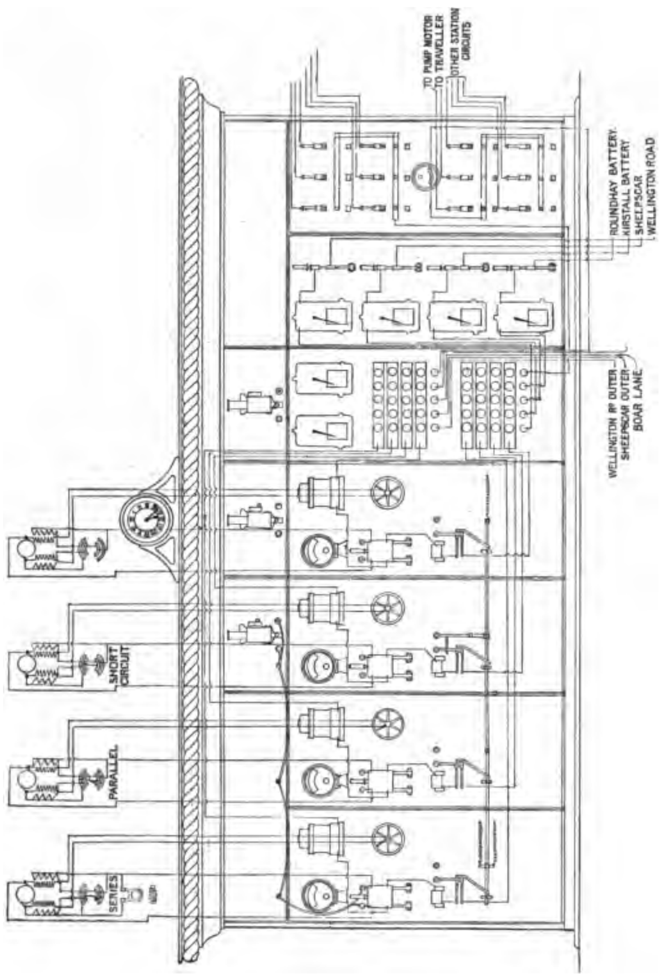

TO PUMP MOTOR
TO TRAVELLER
OTHER STATION CIRCUITS
ROUNDHAY BATTERY
KIRSTALL BATTERY
SHEEPSCAR
WELLINGTON ROAD
WELLINGTON RD OUTER
SHEEPSCAR OUTER
BOAR LANE
SHORT CIRCUIT
PARALLEL
SERIES

FIG. 81.

Panel 5 supports the positive and negative poles of the four dynamos, with the screw-plug board for connecting each machine to the feeders, whether these be for charging batteries or simple feeding on to the line, or for station purposes, such as lighting, and motors for cranes, pumps, etc. Two recording voltmeters, reading up to 10 volts, are mounted on this panel, these being connected each to the middle and extreme ends of the rail return in accordance with the Board of Trade regulations (see Appendix, p. 227, Regulation 7).

Panel 6 supports four circuit breakers and recording ammeters for the four feeders.

Panel 7 is for dealing with the motors and lighting in the station.

An automatic arrangement is provided on one machine, in the first instance, for short circuiting the series coils of the dynamos in the event of there being a tendency to reverse the main current.

Three Kelvin electrostatic voltmeters are placed on the upper central panels, and provision is made for placing these across any of the machine terminals by means of flexible twin wires.

The subject of switchboards and their connections is so wide as to almost demand a separate work. The Author has not space to deal exhaustively with it.

APPENDIX.

STATUTORY RULES AND ORDERS, 1897.

No. 145.

TRAMWAYS, ENGLAND.

R. 363/97.

Regulations, dated February 11, 1897, *made by the Board of Trade under the Provisions of Section* 12 *of the Blackpool Corporation Tramways Order,* 1896, *which was confirmed by the Tramways Orders Confirmation* (No. 1) *Act,* 1896, *for regulating the Employment of Insulated Returns, or of Uninsulated Metallic Returns of Low Resistance; for preventing Fusion or injurious Electrolytic Action of or on Gas or Water Pipes or other Metallic Pipes, Structures, or Substances; and for minimizing as far as is reasonably practicable Injurious Interference with the Electric Wires, Lines, and Apparatus of Parties other than the Promoters, and the Currents therein whether such Lines do or do not use the Earth as a Return.*

Definitions.

In the following regulations—

The expression "energy" means electrical energy.

The expression "generator" means the dynamo or dynamos or other electrical apparatus used for the generation of energy.

The expression "motor" means any electric motor carried on a car and used for the conversion of energy.

The expression "pipe" means any gas or water pipe or other metallic pipe, structure, or substance.

The expression "wire" means any wire or apparatus used for telegraphic, telephonic, electrical signalling, or other similar purposes.

The expression "current" means an electric current exceeding one-thousandth part of one ampere.

The expression "the Promoters" has the same meaning or meanings as in sect. 12 of the Blackpool Corporation Tramways Order, 1896.

Regulations.

1. Any dynamo used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation.

2. One of the two conductors used for transmitting energy from the generator to the motors shall be in every case insulated from earth, and is hereinafter referred to as the "line;" the other may be insulated throughout, or may be uninsulated in such parts and to such extent as is provided in the following regulations, and is hereinafter referred to as the "return."

3. Where any rails on which cars run or any conductors laid between or within three feet of such rails form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated, unless of such sectional area as will reduce the difference of potential between the ends of the uninsulated portion of the return below the limit laid down in Regulation 7.

4. When any uninsulated conductor laid between or within three feet of the rails forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 feet by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity.

5. When any part of a return is uninsulated it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected, through the current-indicator hereinafter mentioned, to two separate earth connections which shall be placed not less than 20 yards apart.

Provided that in place of such two earth connections the Promoters may make one connection to a main for water supply of not less than three inches internal diameter, with the consent of the owner thereof and of the person supplying the water, and provided that where, from the nature of the soil or for other reasons, the Promoters can show to the satisfaction of an inspecting officer of the Board of Trade that the earth connections herein specified cannot be constructed and maintained without undue expense the provisions of this regulation shall not apply.

The earth connections referred to in this regulation shall be constructed, laid, and maintained so as to secure electrical contact with the general mass of earth, and so that an electro-motive force, not exceeding four volts, shall suffice to produce a current of at least two amperes from one earth connection to the other through the earth, and a test shall be made at least once in every month to ascertain whether this requirement is complied with.

No portion of either earth connection shall be placed within six feet of any pipe except a main for water supply of not less than three inches internal diameter which is metallically connected to the earth connections with the consents hereinbefore specified.

6. When the return is partly or entirely uninsulated the Promoters shall in the construction and maintenance of the tramway (*a*) so separate the uninsulated return from the general mass of earth, and from any pipe in the vicinity; (*b*) so connect together the several lengths of the rails; (*c*) adopt such means for reducing the difference produced by the current between the potential of the uninsulated return at any one point and the potential of the uninsulated return at any other point; and (*d*) so maintain the efficiency of the earth connections specified in the preceding regulations as to fulfil the following conditions, viz.:—

(i.) That the current passing from the earth connections through the indicator to the generator shall not at any time exceed either two amperes per mile of single tramway line or five per cent. of the total current output of the station.

(ii.) That if at any time and at any place a test be made by connecting a galvanometer or other current-indicator to the uninsulated return and to any pipe in the vicinity, it shall always be possible to reverse the direction of any current indicated by interposing a battery of three Leclanché cells connected in series if the direction of the current is from the return to the pipe, or by interposing one Leclanché cell if the direction of the current is from the pipe to the return.

In order to provide a continuous indication that the condition (i.) is complied with, the Promoters shall place in a conspicuous position a suitable, properly connected, and correctly marked current-indicator, and shall keep it connected during the whole time that the line is charged.

The owner of any such pipe may require the Promoters to permit him at reasonable times and intervals to ascertain by test that the conditions specified in (ii.) are complied with as regards his pipe.

7. When the return is partly or entirely uninsulated a continuous record shall be kept by the Promoters of the difference of potential during the working of the tramway between the points of

the uninsulated return furthest from and nearest to the generating station. If at any time such difference of potential exceeds the limit of seven volts, the promoters shall take immediate steps to reduce it below that limit.

8. Every electrical connection with any pipe shall be so arranged as to admit of easy examination, and shall be tested by the Promoters at least once in every three months.

9. Every line and every insulated return or part of a return except any feeder shall be constructed in sections not exceeding one-half of a mile in length, and means shall be provided for isolating each such section for purposes of testing.

10. The insulation of the line and of the return when insulated and of all feeders and other conductors, shall be so maintained that the leakage current shall not exceed one-hundredth of an ampere per mile of tramway. The leakage current shall be ascertained daily before or after the hours of running when the line is fully charged. If at any time it should be found that the leakage current exceeds one-half of an ampere per mile of tramway the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within 24 hours. Provided that where both line and return are placed within a conduit this regulation shall not apply.

11. The insulation resistance of all continuously insulated cables used for lines, for insulated returns, for feeders, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of 10 megohms for a length of one mile. A test of the insulation resistance of all such cables shall be made at least once in each month.

12. Where in any case in any part of the tramway the line is erected overhead and the return is laid on or under the ground, and where any wires have been erected or laid before the construction of the tramway in the same or nearly the same direction as such part of the tramway, the Promoters shall, if required so to do by the owners of such wires or any of them, permit such owners to insert and maintain in the Promoters' line one or more induction coils or other apparatus approved by the Promoters for the purpose of preventing disturbance by electric induction. In any case in which the Promoters withhold their approval of any such apparatus the owners may appeal to the Board of Trade, who may, if they think fit, dispense with such approval.

13. Any insulated return shall be placed parallel to and at a distance not exceeding three feet from the line when the line and return are both erected overhead, or eighteen inches when they are both laid underground.

14. In the disposition, connections, and working of feeders the

Promoters shall take all reasonable precautions to avoid injurious interference with any existing wires.

15. The Promoters shall so construct and maintain their system as to secure good contact between the motors and the line and return respectively.

16. The Promoters shall adopt the best means available to prevent the occurrence of undue sparking at the rubbing or rolling contacts in any place and in the construction and use of their generator and motors.

17. In working the cars the current shall be varied as required by means of a rheostat containing at least 20 sections, or by some other equally efficient method of gradually varying resistance.

18. Where the line or return or both are laid in a conduit the following conditions shall be complied with in the construction and maintenance of such conduit:—

(*a*) The conduit shall be so constructed as to admit of easy examination of and access to the conductors contained therein and their insulators and supports.

(*b*) It shall be so constructed as to be readily cleared of accumulation of dust or other *débris*, and no such accumulation shall be permitted to remain.

(*c*) It shall be laid to such falls and so connected to sumps or other means of drainage, as to automatically clear itself of water without danger of the water reaching the level of the conductors.

(*d*) If the conduit is formed of metal, all separate lengths shall be so jointed as to secure efficient metallic continuity for the passage of electric currents. Where the rails are used to form any part of the return they shall be electrically connected to the conduit by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or other means of equal conductivity, at distances apart not exceeding 100 feet. Where the return is wholly insulated and contained within the conduit, the latter shall be connected to earth at the generating station through a high resistance galvanometer suitable for the indication of any contact or partial contact of either the line or the return with the conduit.

(*e*) If the conduit is formed of any non-metallic material not being of high insulating quality and impervious to moisture throughout, and is placed within six feet of any pipe, a non-conducting screen shall be interposed between the conduit and the pipe, of such material and dimensions as shall provide that no current can pass between them without traversing at least six feet of earth, or the circuit itself shall

in such case be lined with bitumen or other non-conducting damp-resisting material in all cases where it is placed within six feet of any pipe.

(*f*) The leakage current shall be ascertained daily, before or after the hours of running when the line is fully charged, and if at any time it shall be found to exceed half an ampere per mile of tramway the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within 24 hours.

19. The Promoters shall, so far as may be applicable to their system of working, keep records as specified below. These records shall, if and when required, be forwarded for the information of the Board of Trade.

Daily Records.

No. of cars running.
Maximum working current.
Maximum working pressure.
Maximum current from the earth connections (*vide* Regulation 6 (i.)).
Leakage current (*vide* Regulations 10 and 18 (*f*)).
Fall of potential in return (*vide* Regulation 7).

Monthly Records.

Condition of earth connections (*vide* Regulation 5).
Insulation resistance of insulated cables (*vide* Regulation 11).

Quarterly Records.

Conductance of joints to pipes (*vide* Regulation 8).

Occasional Records.

Any tests made under provisions of Regulation 6 (ii.).
Localisation and removal of leakage, stating time occupied.
Particulars of any abnormal occurrence affecting the electric working of the tramway.

Signed by order of the Board of Trade this 11th day of February, 1897.

Francis J. S. Hopwood,
Assistant Secretary
Board of Trade.

STATUTORY RULES AND ORDERS, 1896.

No. 747.

TRAMWAY.

Regulations, dated August 17, 1896, *made by the Board of Trade as regards Electrical Power on the Dublin Southern District Tramways.*

R. 13,471/96.

The Board of Trade, under and by virtue of the powers conferred upon them in this behalf, do hereby order that the following regulations for securing to the public reasonable protection against danger in the exercise of the powers conferred by Parliament with respect to the use of electrical power on all or any of the tramways on which the use of such power has been authorised by the Dublin Southern District Tramways Act, 1893 (hereinafter called "the tramways"), be substituted for all other regulations in this behalf contained in any Tramway Act or Tramway Order confirmed by Act of Parliament:

And the Board of Trade do also hereby make the following bye-laws with regard to the use of electrical power on all or any of such tramways.

Regulations.

I. Every motor carriage used on the tramways shall comply with the following requirements, that is to say:—

(*a*) The wheels shall be fitted with brake-blocks, which can be applied by a screw or treadle, or by other means, and there shall be in addition an adequate electric brake.

(*b*) It shall be fitted within six months from the date hereof with a governor which cannot be tampered with by the driver, and which shall operate so as to cut off all electric current from the motors whenever the speed exceeds *ten* miles an hour.

(*c*) It shall be numbered inside and outside, and the number shall be shown in conspicuous parts thereof.

(*d*) It shall be fitted with a suitable fender, which will act efficiently as a life protector, and with a special bell or whistle to be sounded as a warning when necessary.

(*e*) It shall be so constructed as to enable the driver to command the fullest possible view of the road before him.

(*f*) It shall be free from the clatter of machinery, such as to

constitute any reasonable ground of complaint, either to the passengers or to the public, and any machinery under the carriage shall be concealed from view at all points above four inches from the level of the rails.

(*g*) When running between sunset and sunrise, or during fog, it shall carry in front a bright-coloured light.

II. Every trailing carriage used on the tramways shall comply with the following requirements, that is to say:—

(*a*.) The wheels shall be fitted with brake-blocks, which can be applied by a screw or treadle or by other means.

(*b*.) It shall be numbered inside and outside, and the number shall be shown in conspicuous parts thereof.

III. Not more than two carriages shall be coupled together, and when two are so running there shall be, in addition to the conductor, a man on the front platform of the second carriage, whose sole duty it shall be to attend to the brake, means being provided by which the driver can signal to this man when he wishes the brake on the rear carriage to be applied. The carriages shall be connected by double couplings, one of which shall be a screw coupling.

IV. Every carriage used on the tramways shall be so constructed as to provide for the safety of passengers, and for their safe entrance to, exit from, and accommodation in such carriages, and for their protection from the apparatus used for drawing or propelling the carriages.

V. The Board of Trade and their officers may, from time to time, and shall, on the application of the local authority of any of the districts through which the said tramways pass, inspect the carriages used on the tramways, and the working arrangements generally, and may, whenever they think fit, prohibit the use on the tramways of any of them which, in their opinion, are not safe for use.

VI. The speed at which the carriages shall be driven or propelled along the tramways shall not exceed the rate of *eight* miles an hour, and the speed at which the carriages shall pass through facing points, whether fixed or movable, shall not exceed the rate of *four* miles an hour.

VII. The speed shall not exceed the rate of *four* miles an hour in Upper George Street between Mulgrave Street and Mellifont Avenue, or on the road between Merrion Avenue and the boundary between the parishes of Booterstown and Monkstown, and not more than one carriage or two carriages coupled together shall be allowed on the first-mentioned portion of the tramways at one and the same time.

VIII. The passengers shall not have access to any portion of the electric circuit.

IX. All electric mains, leads and connections used must be of ample size, and must be thoroughly insulated and protected by safety fuses or other cut-outs which will operate to break the circuit before the current has risen to an amount which would cause any injurious heating of the conductors, and the length of any safety fuse in the clear shall not be less than two inches.

X. The electrical pressure or difference of potential between any suspended conductors used in connection with the working of the tramways by electrical power and the earth, or between any two such suspended conductors, shall in no case exceed 500 volts continuous pressure.

XI. The suspended conductors used in connection with the working of the tramways by electrical power shall be in no part at a less height from the surface of the street than 17 feet, and shall be securely attached to supports at intervals not exceeding 120 feet.

XII. The line-wire shall be divided up into sections not exceeding (except with the special approval of the Board of Trade) one quarter of a mile in length, between every two of which shall be inserted an emergency switch and a safety fuse or cut-out, constructed to act with a current exceeding the maximum working current by 50 per cent., which apparatus shall be so enclosed as to be inaccessible to pedestrians.

XIII. The electrical pressure between the conductors in any electric line or between any such conductor and the earth shall not in any case exceed 3000 volts.

XIV. All electric lines laid for the purpose of supply to transforming stations on the "three-phase system" shall have their conductors arranged concentrically, the outer conductor being efficiently connected with earth at the generating station, but insulated at all other points; and the thickness of insulation between the several conductors of any such electric line shall not be less in parts of an inch than the number obtained by dividing the number expressing the maximum electrical pressure in volts by 20,000. No such electric line shall be brought into use unless the insulation of every part thereof has withstood the continuous application during one hour of twice the maximum pressure to which it is intended to be subjected in use.

XV. The sectional area of the conductor in any electric line laid or erected in any street after the date of these regulations shall not be less than the area of a circle of one-tenth of an inch diameter, and where the conductor is formed of a strand of wires, each separate wire shall be at least as large as No. 20 standard wire gauge: Provided that this regulation shall not apply to any electric line connected to the rails for the purpose of measuring the fall of

potential in the return and not otherwise connected with the electric circuit.

XVI. No part of any electric line shall be used for the transmission of more than 300,000 watts, except with the consent in writing of the Board of Trade, and efficient means shall be provided to prevent this limit being at any time exceeded.

XVII.* All electrical conductors fixed upon the carriages in connection with the "trolley-wheel" shall be formed of flexible cables protected by indiarubber insulation of the highest quality, and additionally protected wherever they are adjacent to any metal so as to avoid risk of the metal becoming charged.

The insulation resistance between these conductors and the "trolley standard" and the metal fittings on the carriages respectively shall be tested daily with the full working electrical pressure, and shall not be permitted to fall below the following amounts respectively, viz.:—

Between conductors and trolley standard - - 10 megohms.
Between conductors and metal fittings - - - 1 megohm.

XVIII.* All metal fittings upon the roofs of the carriages within six feet of the trolley standard shall be carefully covered with insulating material to a thickness of at least 16th inch, and this covering shall be constantly maintained in efficient condition.

XIX. An emergency cut-off switch shall be provided and fixed so as to be conveniently reached by the driver in case of any failure of action of the controller switch.

XX. Efficient guard wires shall be erected and maintained at all places where telegraph or telephone wires cross above the electric conductors of the tramways.

XXI. Where any portion of any electric line or any support for an electric line is exposed in such a position as to be liable to injury from lightning, it shall be efficiently protected against such injury.

XXII. Where any accident by explosion or fire, or any other accident of such kind as to have caused or to be likely to have caused loss of life or personal injury has occurred in connection with the electric working of the tramways, immediate notice thereof shall be given to the Board of Trade.

* The words "and additionally . . . becoming charged," and the words, "and shall not be permitted . . . 1 megohm," in this Rule are omitted in the Regulations of November 19, 1896, for the Hartlepool Tramways. See Regulation XVII., p. 239.

* The words in this Rule have been omitted in the Hartlepool Tramways Regulations, date November 19, 1896, and others substituted. See Regulation XVIII., p. 239.

Penalty.

NOTE.—Any company or person using electrical power on the tramways contrary to any of the above regulations is, for every such offence, subject to a penalty not exceeding £10, and also in the case of a continuing offence, to a further penalty not exceeding £5 for every day after the first during which such offence continues.

Byelaws.

I. The special bell or whistle shall be sounded by the driver of the carriage from time to time when it is necessary as a warning.

II. Whenever it is necessary to avoid impending danger, the carriages shall be brought to a standstill.

III. The entrance to and exit from the carriages shall be by the hindermost or conductor's platform.

IV. The carriages shall be brought to a standstill immediately before passing round the spot known as Hynes Corner.

V. A printed copy of these regulations and byelaws shall be kept in a conspicuous position inside of each carriage in use on the tramways.

Penalty.

NOTE.—Any person or corporation offending against or committing a breach of any of these byelaws is liable to a penalty not exceeding forty shillings.

The provisions of the Tramways Act, 1870, with respect to the recovery of penalties, are applicable to the penalties for the breach of these regulations or byelaws.

Signed by order of the Board of Trade, this 17th day of August, 1896.

Francis J. S. Hopwood,
An Assistant Secretary to the
Board of Trade.

STATUTORY RULES AND ORDERS, 1896.

No. 997.

TRAMWAY.

Regulations, dated November 19, 1896, *made by the Board of Trade as regards Electrical Power on the Hartlepool Tramways.*

R. 15,846/96.

The Board of Trade, under and by virtue of the powers conferred upon them in this behalf, do hereby order that the following regulations for securing to the public reasonable protection against danger in the exercise of the powers conferred by Parliament with respect to the use of mechanical power on all or any of the tramways on which the use of such power has been authorized by the Hartlepool Tramways Order, 1883, which was confirmed by the Tramways Orders Confirmation (No. 1) Act, 1883 (hereinafter called "the tramways"), be substituted for all other regulations in this behalf contained in any Tramway Act or Tramway Order confirmed by Act of Parliament:

And the Board of Trade do also hereby make the following byelaws with regard to the use of mechanical power on all or any of such tramways.

Regulations.

I. Every motor carriage used on the tramways shall comply with the following requirements, that is to say:—

(*a*) The wheels shall be fitted with brake-blocks, which can be applied by a screw or treadle, or by other means, and there shall be in addition an adequate electric brake.

(*b*) It shall be fitted within six months from the date hereof, or within such further period as the Board of Trade may prescribe, with a governor which cannot be tampered with by the driver, and which shall operate so as to cut off all electric current from the motors whenever the speed exceeds ten miles an hour.

(*c*) It shall be numbered inside and outside, and the number shall be shown in conspicuous parts thereof.

(*d*) It shall be fitted with a suitable fender, which will act efficiently as a life protector, and with a special bell to be sounded as a warning when necessary.

(*e*) It shall be so constructed as to enable the driver to command the fullest possible view of the road before him.

(*f*) It shall be free from the clatter of machinery, such as to constitute any reasonable ground of complaint either to the passengers or to the public, and any machinery under the carriage shall be concealed from view at all points above four inches from the level of the rails.

(*g*) When running between sunset and sunrise, or during fog, it shall carry in front a bright-coloured light.

II. Every trailing carriage used on the tramways shall comply with the following requirements, that is to say:—

(*a*) The wheels shall be fitted with brake-blocks, which can be applied by a screw or treadle or by other means.

(*b*) It shall be numbered inside and outside, and the number shall be shown in conspicuous parts thereof.

III. Not more than two carriages shall be coupled together, and when two are so running there shall be, in addition to the conductor, a man on the front platform of the second carriage, whose sole duty it shall be to attend to the brake, means being provided by which the driver can signal to this man when he wishes the brake on the rear carriage to be applied. The carriages shall be connected by double couplings, one of which shall be a screw coupling.

IV. Every carriage used on the tramways shall be so constructed as to provide for the safety of passengers, and for their safe entrance to, exit from, and accommodation in such carriages, and for their protection from the apparatus used for drawing or propelling the carriages.

V. The Board of Trade and their officers may, from time to time, and shall, on the application of the local authority of any of the districts through which the said tramways pass, inspect the carriages used on the tramways, and the working arrangements generally, and may, whenever they think fit, prohibit the use on the tramways of any of them which, in their opinion, are not safe for use.

VI. The speed at which the carriages shall be driven or propelled along the tramways shall not exceed the rate of eight miles an hour, and the speed at which the carriages shall pass through facing points, whether fixed or movable, shall not exceed the rate of four miles an hour.

VII. The speed shall not exceed the rate of four miles an hour at the following places:—

(*a*) In Northgate Street, Hartlepool, between Union Street and Tweddle Street.

(*b*) On the double line on each side of the bridge carrying the North-Eastern Railway over Cleveland Road.

(*c*) In front of Christ Church Schools, West Hartlepool.

VIII. No two carriages shall enter any passing-place from opposite directions at one and the same time.

IX. Notices shall be exhibited on each side of the two railway bridges crossing the tramways, having in characters legible to passengers the words:—

It is dangerous to touch the electric wires.

X. The passengers shall not have access to any portion of the electric circuit.

XI. All electric mains, leads and connections used must be of ample size and must be thoroughly insulated and protected by safety fuses or other cut-outs which will operate to break the circuit before the current has risen to an amount which would cause any injurious heating of the conductors, and the length of any safety fuse in the clear shall not be less than two inches.

XII. The electrical pressure or difference of potential between any suspended conductors used in connection with the working of the tramways by electrical power and the earth, or between any two such suspended conductors, shall in no case exceed 500 volts continuous pressure.

XIII. The suspended conductors used in connection with the working of the tramways by electrical power shall be in no part at a less height from the surface of the street than 17 feet, and shall be securely attached to supports at intervals not exceeding 120 feet.

XIV. The line-wire shall be divided up into sections not exceeding (except with the special approval of the Board of Trade) one quarter of a mile in length, between every two of which shall be inserted an emergency switch and a safety fuze or cut-out constructed to act with a current exceeding the maximum working current by 50 per cent., which apparatus shall be so enclosed as to be inaccessible to pedestrians.

XV. The sectional area of the conductor in any electric line laid or erected in any street after the date of these regulations shall not be less than the area of a circle of one-tenth of an inch diameter, and where the conductor is formed of a strand of wires, each separate wire shall be at least as large as No. 20 standard wire gauge: Provided that this regulation shall not apply to any electric line connected to the rails for the purpose of measuring the fall of potential in the return and not otherwise connected with the electric circuit.

XVI. No part of any electric line shall be used for the transmission of more than 300,000 watts, except with the consent in writing of the Board of Trade, and efficient means shall be provided to prevent this limit being at any time exceeded.

XVII. All electrical conductors fixed upon the carriages in connection with the "trolley-wheel" shall be formed of flexible cables protected by indiarubber insulation of the highest quality.

The insulation resistance between these conductors and the "trolley standard" and the metal fittings on the carriages respectively shall be tested daily with the full working electrical pressure.

XVIII. The "trolley standard" shall be maintained in efficient metallic connection with the metal fittings on the roof of the car and with the metal frame of the car.

XIX. An emergency cut-off switch shall be provided and fixed so as to be conveniently reached by the driver in case of any failure of action of the controller switch.

XX. Efficient guard wires shall be erected and maintained at all places where telegraph or telephone wires cross above the electric conductors of the tramway.

XXI. Where any portion of any electric line or any support for an electric line is exposed in such a position as to be liable to injury from lightning, it shall be efficiently protected against such injury.

XXII. Where any accident by explosion or fire, or any other accident of such kind as to have caused or to be likely to have caused loss of life or personal injury has occurred in connection with the electric working of the tramways, immediate notice thereof shall be given to the Board of Trade.

Penalty.

NOTE.—Any company or person using electrical power on the tramways contrary to any of the above regulations is, for every such offence, subject to a penalty not exceeding £10, and also in the case of a continuing offence, to a further penalty not exceeding £5 for every day after the first during which such offence continues.

Byelaws.

I. The special bell shall be sounded by the driver of the carriage from time to time when it is necessary as a warning.

II. Whenever it is necessary to avoid impending danger, the carriages shall be brought to a standstill.

III. The entrance to and exit from the carriages shall be by the hindermost or conductor's platform.

IV. The carriages shall be brought to a standstill at the following points:—

(*a*) Throston Iron Bridge.

(*b*) The railway level crossing in Cleveland Road, if and when the railway is used for traffic.
(*c*) The junction of Middleton Road and Clarence Road.
(*d*) The corner by the police station in Church Street, West Hartlepool.
(*e*) The corner by the fountain in Church Street.
(*f*) The intersection of Whitby Street with Church Street.

V. A printed copy of these regulations and byelaws shall be kept in a conspicuous position inside of each carriage in use on the tramways.

Penalty.

NOTE.—Any person or corporation offending against or committing a breach of any of these byelaws is liable to a penalty not exceeding forty shillings.

The provisions of the Tramways Act, 1870, with respect to the recovery of penalties, are applicable to the penalties for the breach of these regulations or byelaws.

Signed by order of the Board of Trade, this 19th day of November, 1896.

Francis J. S. Hopwood,

An Assistant Secretary to the Board of Trade.

LOCOMOTIVES ON HIGHWAYS ACT, 1896.

REGULATIONS.—GENERAL.

To THE COUNTY COUNCILS of the several ADMINISTRATIVE COUNTIES in ENGLAND and WALES :—

To the Councils of the several County Boroughs in England and Wales ;—
To the Sanitary Authorities of the several Sanitary Districts in the Administrative County of London ;—
To the Urban District Councils of the several Urban Districts in England and Wales ;—
To the Rural District Councils acting as the Highway Authorities in Rural Districts in England and Wales ;—
And to all others whom it may concern.

Whereas by Section 6 of the Locomotives on Highways Act, 1896 (herein-after called "the Act"), it is enacted that—

"(1) The Local Government Board may make regulations "with respect to the use of light locomotives on highways, and "their construction, and the conditions under which they may be "used.

"(2) * * * All regulations under this section "shall have full effect notwithstanding anything in any other Act, "whether general or local, or any byelaws or regulations made "thereunder."

And whereas by Section 2 of the Act it is enacted that—

"During the period between one hour after sunset and one "hour before sunrise, the person in charge of a light locomotive "shall carry attached thereto a lamp so constructed and placed as "to exhibit a light in accordance with the regulations to be made "by the Local Government Board."

And whereas by Section 7 of the Act it is enacted that—

"A breach of any * * regulation made under this "Act, * * * may, on summary conviction, be "punished by a fine not exceeding ten pounds."

Now Therefore, in pursuance of the powers given to Us by the Act, and by any other Statutes in that behalf, We, the Local Government Board, Do by this Our Order make the following Regulations with respect to the use of Light Locomotives on Highways, and their construction, and the conditions under which they may be used, and Direct that the same shall have effect on and after the Fourteenth day of November, One thousand eight hundred and ninety-six:

Article I.—In this order—

The expression "carriage" includes a waggon, cart, or other vehicle.

The expression "horse" includes a mule or other beast of draught or burden, and the expression "cattle" includes sheep.

The expression "Light Locomotive" means a vehicle propelled by mechanical power which is under three tons in weight unladen, and is not used for the purpose of drawing more than one vehicle (such vehicle with its locomotive not exceeding in weight unladen four tons), and is so constructed that no smoke or visible vapour is emitted therefrom except from any temporary or accidental cause.

In calculating for the purposes of this Order the weight of a vehicle unladen, the weight of any water, fuel, or

accumulators used for the purpose of propulsion shall not be included.

Article II.—No person shall cause or permit a Light Locomotive to be used on any highway, or shall drive or have charge of a Light Locomotive when so used, unless the conditions hereinafter set forth shall be satisfied, namely,—

(1) The Light Locomotive, if it exceeds in weight unladen five hundredweight, shall be capable of being so worked that it may travel either forwards or backwards.

(2) The Light Locomotive shall not exceed six and a half feet in width, such width to be measured between its extreme projecting points.

(3) The tyre of each wheel of the Light Locomotive shall be smooth, and shall, where the same touches the ground, be flat and of the width following, namely,—

(*a*) if the weight of the Light Locomotive unladen exceeds fifteen hundredweight, but does not exceed one ton, not less than two and a half inches;

(*b*) if such weight exceeds one ton, but does not exceed two tons, not less than three inches;

(*c*) if such weight exceeds two tons, not less than four inches.

Provided that where a pneumatic tyre or other tyre of a soft and elastic material is used, the tyre may be round or curved, and there may be upon the same projections or bosses rising above the surface of the tyre if such projections or bosses are of the same material as that of the tyre itself or of some other soft and elastic material. The width of the tyre shall, for the purpose of this proviso, mean the extreme width of the soft and elastic material on the rim of the wheel when not subject to pressure.

(4) The Light Locomotive shall have two independent brakes in good working order, and of such efficiency that the application of either to such Locomotive shall cause two of its wheels on the same axle to be so held that the wheels shall be effectually prevented from revolving, or shall have the same effect in stopping the Light Locomotive as if such wheels were so held.

Provided that in the case of a bicycle this Regulation shall apply as if, instead of two wheels on the same axle, one wheel was therein referred to.

(5) The Light Locomotive shall be so constructed as to admit of its being at all times under such control as not to cause

undue interference with passenger or other traffic on any highway.

(6) In the case of a Light Locomotive drawing or constructed to draw another vehicle, or constructed or used for the carriage of goods, the name of the owner and the place of his abode or business, and in every such case and in the case of every Light Locomotive weighing unladen one ton and a half or upwards, the weight of the Light Locomotive unladen shall be painted in one or more straight lines upon some conspicuous part of the right or off side of the Light Locomotive in large legible letters in white upon black or black upon white, not less than one inch in height.

(7) The Light Locomotive and all the fittings thereof shall be in such a condition as not to cause, or to be likely to cause, danger to any person on the Light Locomotive or on any highway.

(8) There shall be in charge of the Light Locomotive when on any highway a person competent to control and direct its use and movement.

(9) The lamp to be carried attached to the Light Locomotive in pursuance of Section 2 of the Act shall be so constructed and placed as to exhibit, during the period between one hour after sunset and one hour before sunrise, a white light visible within a reasonable distance in the direction towards which the Light Locomotive is proceeding or is intended to proceed, and to exhibit a red light so visible in the reverse direction. The lamp shall be placed on the extreme right or off-side of the Light Locomotive in such a position as to be free from all obstruction to the light.

Provided that this Regulation shall not extend to any bicycle, tricycle, or other machine to which Section 85 of the Local Government Act, 1888, applies.

Article III.—No person shall cause or permit a Light Locomotive to be used on any highway for the purpose of drawing any vehicle, or shall drive or have charge of a Light Locomotive when used for such purpose unless the conditions hereinafter set forth shall be satisfied, namely—

(1) Regulations (2), (3), (5), and (7) of Article II. of this Order shall apply as if the vehicle drawn by the Light Locomotive was therein referred to instead of the Light Locomotive itself, and Regulation (6) of the Article shall apply as if such vehicle was a Light Locomotive constructed for the carriage of goods.

(2) The vehicle drawn by the Light Locomotive, except where

the Light Locomotive travels at a rate not exceeding four miles an hour, shall have a brake in good working order of such efficiency that its application to the vehicle shall cause two of the wheels of the vehicle on the same axle to be so held that the wheels shall be effectually prevented from revolving, or shall have the same effect in stopping the vehicle as if such wheels were so held.

(3) The vehicle drawn by the Light Locomotive shall, when under the last preceding regulation a brake is required to be attached thereto, carry upon the vehicle a person competent to apply efficiently the brake: Provided that it shall not be necessary to comply with this Regulation if the brakes upon the Light Locomotive by which the vehicle is drawn are so constructed and arranged that neither of such brakes can be used without bringing into action simultaneously the brake attached to the vehicle drawn, or if the brake of the vehicle drawn can be applied from the Light Locomotive independently of the brakes of the latter.

Article IV.—Every person driving or in charge of a Light Locomotive when used on any highway shall comply with the Regulations hereinafter set forth, namely—

(1) He shall not drive the Light Locomotive at any speed greater than is reasonable and proper having regard to the traffic on the highway, or so as to endanger the life or limb of any person, or to the common danger of passengers.

(2) He shall not under any circumstances drive the Light Locomotive at a greater speed than twelve miles an hour. If the weight unladen of the Light Locomotive is one ton and a half and does not exceed two tons, he shall not drive the same at a greater speed than eight miles an hour, or if such weight exceeds two tons at a greater speed than five miles an hour.

Provided that whatever may be the weight of the Light Locomotive, if it is used on any highway to draw any vehicle, he shall not under any circumstances drive it at a greater speed than six miles an hour.

Provided also that this Regulation shall only have effect during six months from the date of this Order, and thereafter until We otherwise direct.

(3) He shall not cause the Light Locomotive to travel backwards for a greater distance or time than may be requisite for purposes of safety.

(4) He shall not negligently or wilfully cause any hurt or damage to any person, carriage, horse, or cattle, or to any goods

conveyed in any carriage on any highway, or, when on the Light Locomotive, be in such a position that he cannot have control over the same, or quit the Light Locomotive without having taken due precautions against its being started in his absence, or allow the Light Locomotive or a vehicle drawn thereby to stand on such highway so as to cause any unnecessary obstruction thereof.

(5) He shall when meeting any carriage, horse, or cattle keep the Light Locomotive on the left or near side of the road, and when passing any carriage, horse, or cattle proceeding in the same direction keep the Light Locomotive on the right or off side of the same.

(6) He shall not negligently or wilfully prevent, hinder, or interrupt the free passage of any person, carriage, horse, or cattle on any highway, and shall keep the Light Locomotive and any vehicle drawn thereby on the left or near side of the road for the purpose of allowing such passage.

(7) He shall, whenever necessary, by sounding the bell or other instrument required by Section 3 of the Act, give audible and sufficient warning of the approach or position of the Light Locomotive.

(8) He shall on the request of any police constable, or of any person having charge of a restive horse, or on any such constable or person putting up his hand as a signal for that purpose, cause the Light Locomotive to stop and to remain stationary so long as may be reasonably necessary.

Article V.—If the Light Locomotive is one to which Regulation (6) of Article II. applies, and the particulars required by that Regulation are not duly painted thereon, or if the Light Locomotive is one to which that Regulation does not apply, the person driving or in charge thereof shall, on the request of any constable, or on the reasonable request of any other person, truly state his name and place of abode, and the name of the owner, and the place of his abode or business.

This order may be cited as "The Light Locomotives on Highways Order, 1896."

Given under the Seal of Office of the Local Government Board, this Ninth day of November, in the year One thousand eight hundred and ninety-six.

L. S.

HENRY CHAPMAN, *President.*
HUGH OWEN, *Secretary.*

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